SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

1958 Literature Review, Part II—Research Committee Industrial Wastes, Including Radioactivity

Treatment Cost Considerations—Saxton

Radioactivity in Streams—Harris

Petrochemical Wastes—McRae

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Operator's Corner

Deeds and Data, 1958 Operators' Forum

JUNE 1959—VOL. 31, No. 6

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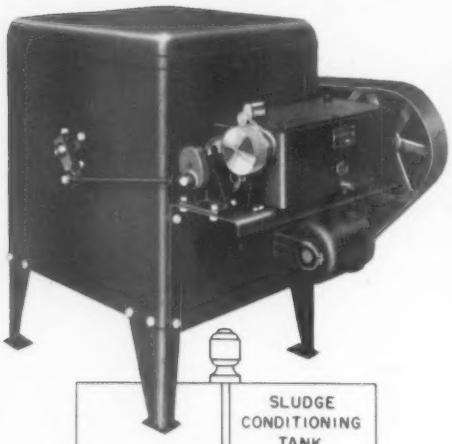

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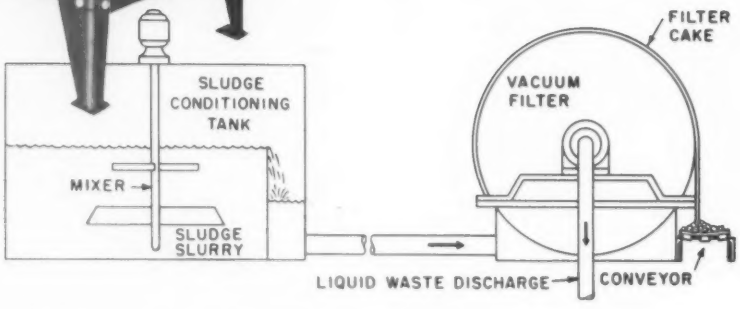

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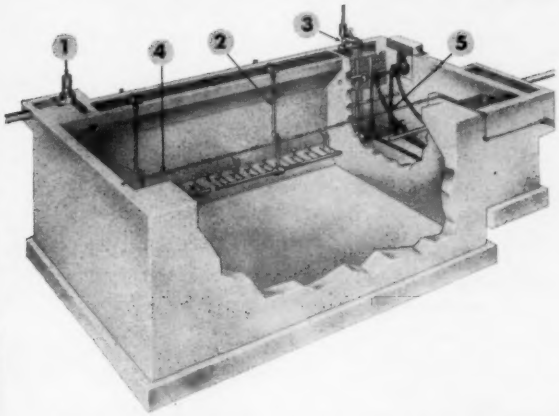

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Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 **June 1959** **Number 6**

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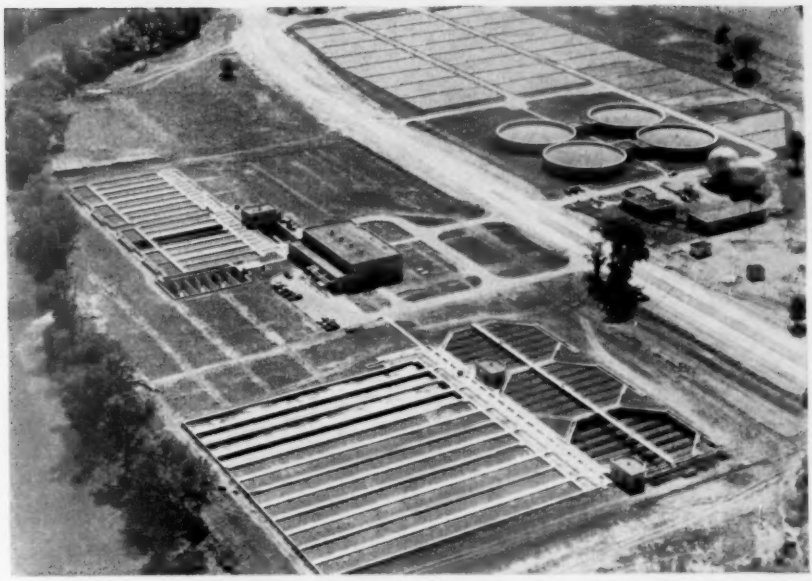

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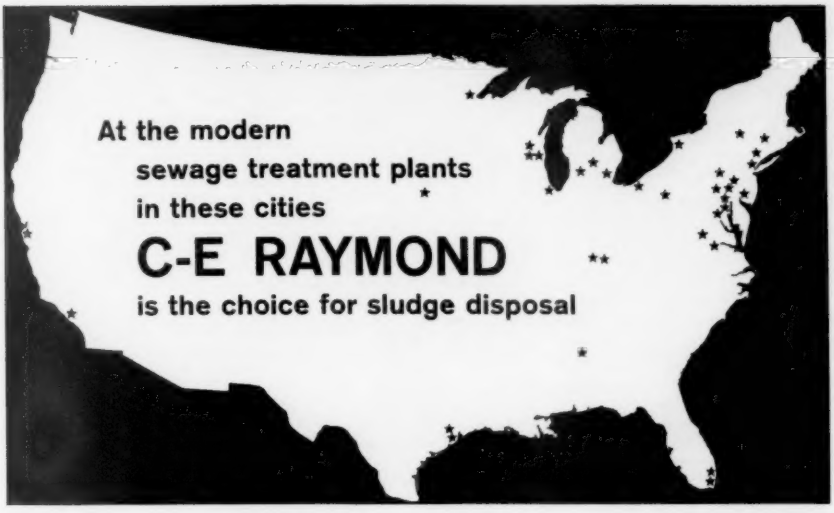

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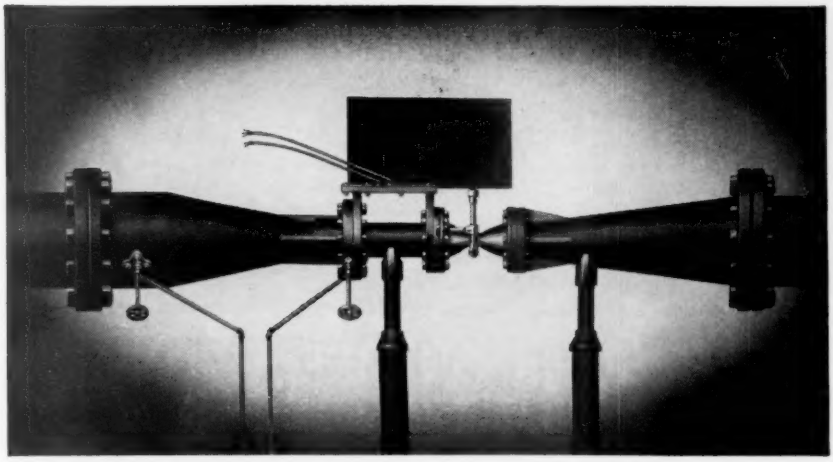

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Maryland-Delaware Water and Sewage Assn.	Commander Hotel Ocean City, Md.	June 3–5, 1959
New York Sewage and Industrial Wastes Assn. (*Spring Meeting*)	Saranac Inn Upper Saranac Lake, N. Y.	June 8–9, 1959
Ohio Sewage and Industrial Wastes Treatment Conf.	Netherland Hilton Cincinnati, Ohio	June 17–19, 1959
Iowa Sewage and Industrial Wastes Assn.	Roosevelt Hotel Cedar Rapids, Iowa	June 17–19, 1959
Institute of Sewage Purification	Bournemouth, England	June 23–26, 1959
Central States Sewage and Industrial Wastes Assn.	Pick Nicollet Hotel Minneapolis, Minn.	June 24–26, 1959
Pennsylvania Sewage and Industrial Wastes Assn.	Pennsylvania State University University Park, Pa.	Aug. 12–14, 1959
South Dakota Water and Sewage Works Conf.	Marvin Hughitt Hotel Huron, S. Dak.	Sept. 2–4, 1959
Rocky Mountain Sewage and Industrial Wastes Assn.	Jackson Lodge Jackson, Wyo.	Sept. 8–10, 1959
Georgia Water and Sewage Assn.	Georgia Inst. of Technology Atlanta, Ga.	Sept. 9–11, 1959

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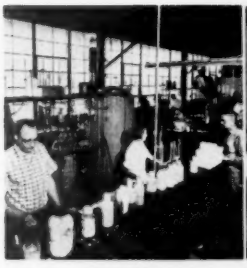

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...these have been the objectives of INFILCO for many years. The Research and Development Division has been expanded to accelerate new developments in water and waste treatment – and to work with you and your engineer for the solution of specific problems.

INFILCO INC.
General Offices
Tucson, Arizona

Field offices throughout the United States and other countries

INFILCO

BIG AD CAMPAIGN WARNS OF GROWING WATER PROBLEM!

Urges local support for better water systems

Cast Iron Pipe Research Association offers local plan-of-action booklet

Here's help for you and everyone else directly concerned with the supply, treatment and distribution of water—help that will acquaint the people in your town with the vital importance of this growing problem.

On the opposite page you see the second in a series of advertisements, this one appearing in April *Reader's Digest*. Placed by the Cast Iron Pipe Research Association, these striking advertisements point out to Mr. and Mrs. America how much we depend on a good water system and why we can no longer take it for granted.

Similar advertising will appear regularly in *U. S. News & World Report*, *Nation's Business*, *Better Homes & Gardens*, *American Home* and *Sunset* magazines to carry this public service message to millions of civic leaders and homeowners.

Free Local How-to-Help Booklet

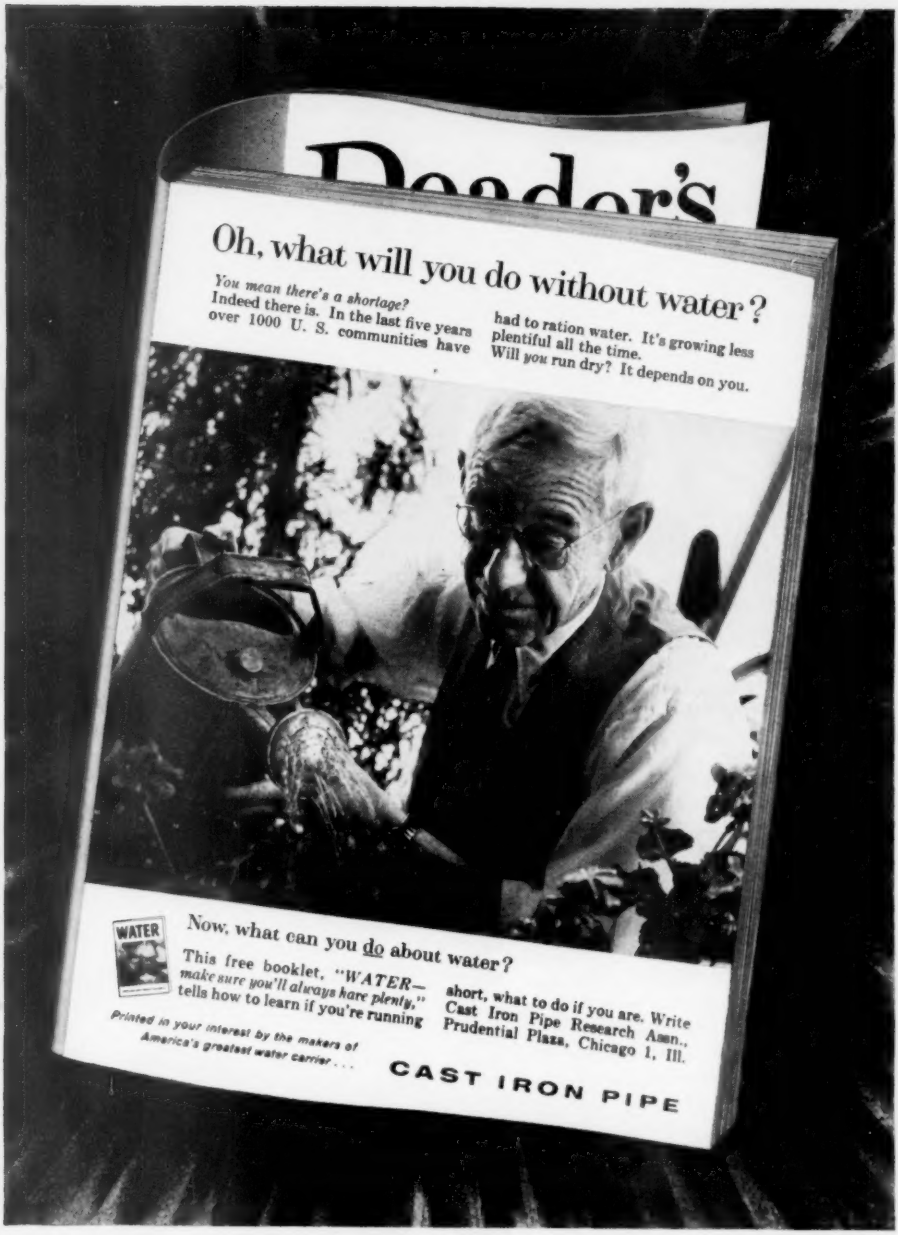
These ads offer a free booklet telling about the water problem. It shows how responsible citizens can acquaint themselves with the needs of their community. It also gives a step-by-step outline of action, telling how they can help their officials extend and improve the local water system through more adequate rate structures or financing.

Let us send you a free copy of this new booklet. Write to Thos. F. Wolfe, Managing Director, Cast Iron Pipe Research Association, 3440 Prudential Plaza, Chicago 1, Ill.

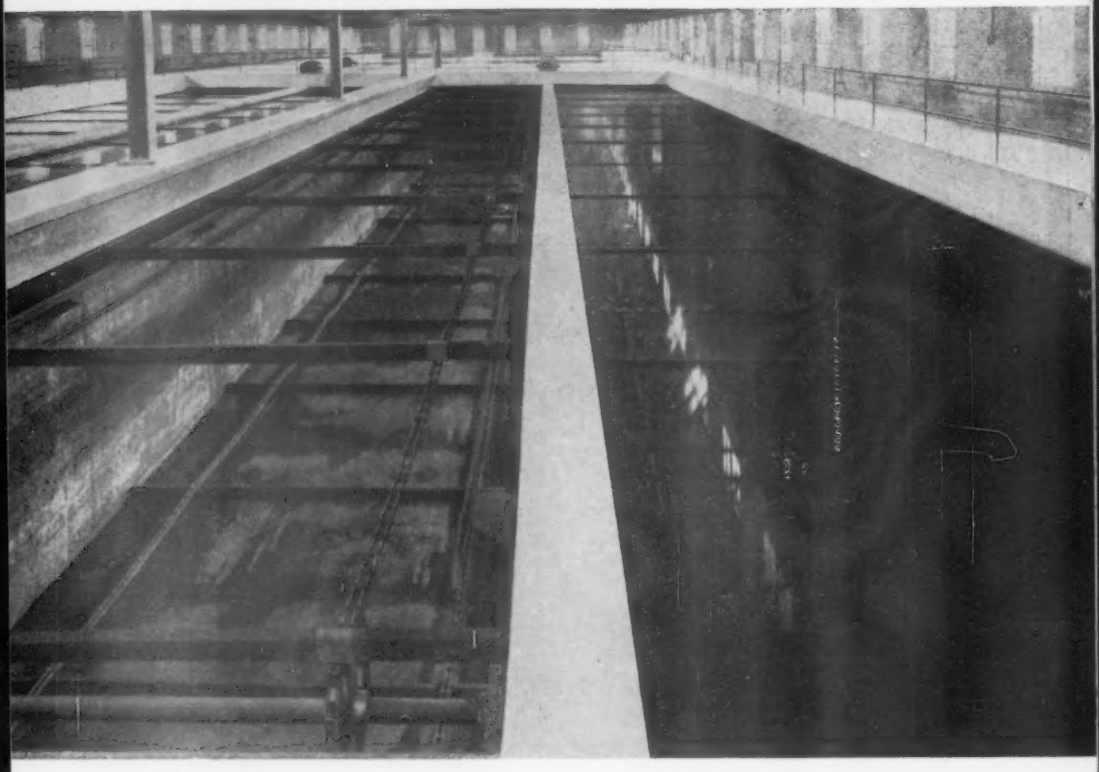
Three reasons why cast iron pipe is America's greatest water carrier:

1. More miles of underground cast iron water mains are now in use than of all other kinds of pipe combined.
2. More miles of cast iron water mains are now being purchased and laid than of any other kind of pipe.
3. Impartial surveys prove that today's consulting engineers and water utility officials prefer cast iron pipe for underground water distribution by an overwhelming majority.

CAST IRON PIPE


Reader's
Oh, what will you do without water?
You mean there's a shortage? Indeed there is. In the last five years over 1000 U. S. communities have had to ration water. It's growing less plentiful all the time. Will you run dry? It depends on you.
Now, what can you do about water?
This free booklet, "WATER—make sure you'll always have plenty," tells how to learn if you're running short, what to do if you are. Write Cast Iron Pipe Research Assn., Prudential Plaza, Chicago 1, Ill.
WATER
Printed in your interest by the makers of America's greatest water carrier . . .
CAST IRON PIPE

Rex Record at Racine, Wisconsin



Rex Primary Sludge Collectors at the Racine, Wis., sewage disposal plant. Rex Equipment at this plant includes longitudinal and cross collectors... grit collectors and washers... bar screens and triturators.

181,800 hours of continuous operation... with original equipment

181,800 hours of continuous operation... almost *21* years of service 365 days a year, 24 hours a day... that's the record Rex Conveyor Sludge Collectors have established at the Racine, Wisconsin, sewage treatment plant. Here's definite proof of the design and manufacturing superiority of Rex Equipment. Rex Z-Metal Chains, Temperim sprockets, case-hardened centralized wearing shoes, accurately made redwood flights and self-aligning underwater bearings, plus balanced strength, flexible design and the other Rex "extras," put extra life into Racine's Rex Conveyor Sludge Collectors... both longitudinal and cross collectors.

If you're interested in record service like Racine's why not investigate Rex Waste Treatment Equipment. In the broad Rex line, there's exactly the right choice for you... from screening to clarification. For all the facts, write CHAIN Belt Company, 4606 West Greenfield Avenue, Milwaukee 1, Wisconsin.

Thomas T. Hay, superintendent of Racine Sewage Treatment Plant since 1941. His careful operation and maintenance practices have been a major factor in this record performance. Consulting Engineers: Alvord, Burdick & Howson, Chicago, Illinois.

REX®

CHAIN BELT COMPANY

Weir plates of Everdur control water flow in Toronto's new Humber plant

These corrosion-resistant Everdur weir plates will handle *50 million gallons* of water every day at the new Humber sewage treatment plant.

Easy fabrication. Everdur weir plates are being joined by arc welding prior to installation.

EVERDUR RESISTS CORROSION. Installations of Everdur sewage-treatment and waterworks equipment in the United States have been in service without replacement for 30 years and longer.

EVERDUR IS TOUGH. Everdur, Anaconda's group of copper-silicon alloys, also possesses high physical strength and resistance to wear and abrasion—so that wrought equipment can be designed with lighter weight.

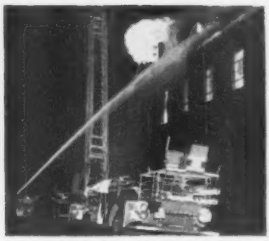
EVERDUR IS READILY FABRICATED. Everdur alloys are available for hot or cold working, welding, free machining, forging and casting—and can be supplied in plates, sheets, rods, bars, wire, tubes, electrical conduit, and casting ingots.

WRITE FOR PUBLICATION E-11—or for assistance from the Technical Department in selecting the correct material for your equipment. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5986

EVERDUR® Anaconda's Family of Copper-Silicon Alloys
MADE BY THE AMERICAN BRASS COMPANY

STRONG • WELDABLE • WORKABLE • CORROSION-RESISTANT

THE BUCKET BRIGADE of earlier days was willing but ineffective. Once started, a blaze usually raged to complete destruction.



MODERN FIRE FIGHTING APPARATUS, fed by a dependable water system of cast iron pipe, uses high pressure to place water where needed. Losses are minimized.

U.S. PIPE

FOR WATER, SEWERAGE AND

U. S. PIPE AND FOUNDRY COMPANY

but better than ever today!

Top quality of U. S. Pipe assured by rigid mine-to-main supervision

Cast iron pipe may look alike.

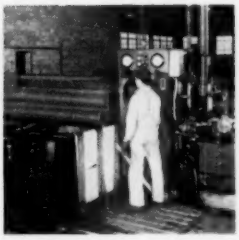
But there's a difference... an important difference to the men charged with keeping our water running smoothly— the nation's water officials.

This is the care and precision with which pipe is made. U. S. Pipe, for example, controls every production step. From mining iron ore, through the blast furnace to final casting, all U. S. Pipe is continuously checked for quality.

Result? Even greater life and dependability for the U. S. Pipe that carries so much of America's water.

COAL is discharged mechanically into mine cars for transportation to the surface.

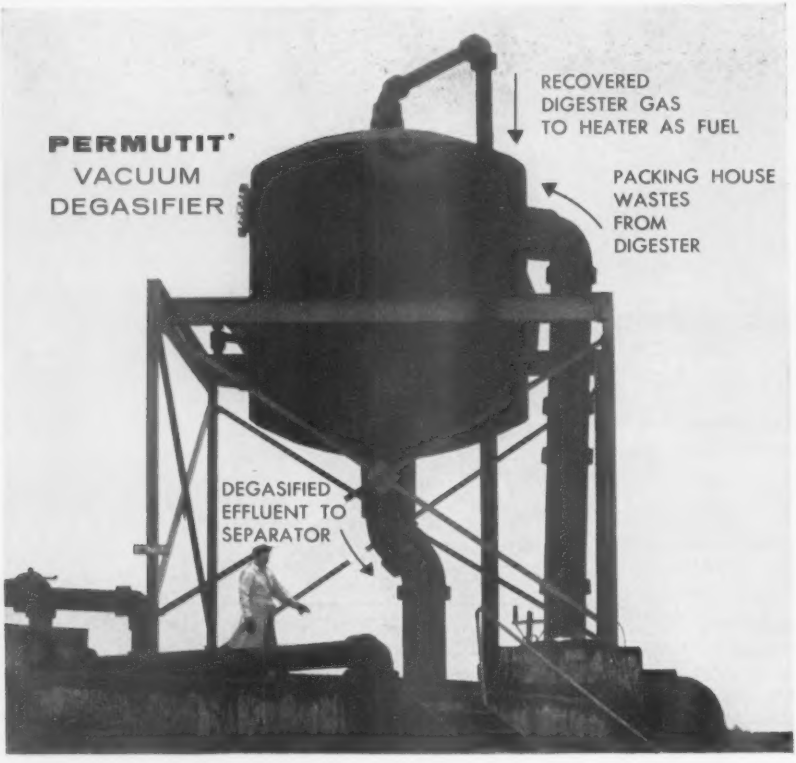
NEWLY CAST 24-inch pipe 18 feet long just removed from centrifugal casting machine.



EACH LENGTH of U. S. cast iron pipe is tested hydrostatically to a minimum of 500 psi on the production line.

INDUSTRIAL SERVICE CAST IRON

Birmingham 2, Ala. *A wholly integrated producer from mines and blast furnaces to finished pipe.*



FLUIDICS AT WORK

How Wilson & Company gets faster waste treatment and lowers fuel costs

When you can expand a process with a piece of equipment that saves you money every day, you're fast on the road to real economy.

Wilson & Company accomplished this with the anaerobic digestion process they use for treating liquid packing house wastes.

They put a Permutit vacuum degasifier between the digester and the separator and promptly cut cost two ways:

More capacity. Separator detention time is much shorter now, because solids settle completely and rapidly in the degasified liquid. Without gas bubbles, flotation is practically eliminated.

Lower fuel costs. The degasifier reclaims combustible methane gas produced by bacteria in the digester. This methane (containing a little CO_2 and H_2S) is then used as fuel for heating waste in the digester.

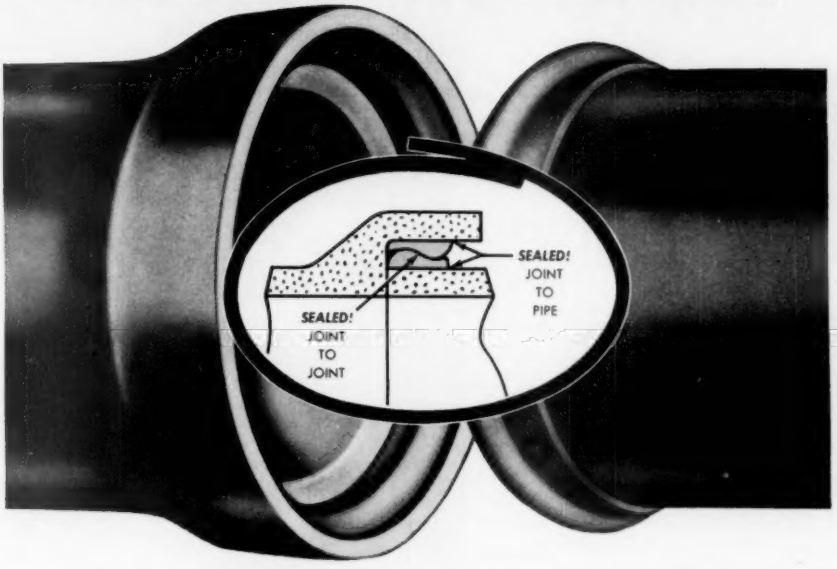
Smart answers like this are easy to come by when you take advantage of Permutit's engineering experience with *all* major types of solids-separation equipment, including precipitation and flotation units, centrifuges, filters, evaporators, and degasifiers.

When you need help or information on such problems, write to our Permutit Division, Dept. SI-69, 50 West 44th Street, New York 36, N. Y. . . . or Permutit Company of Canada, Ltd., Toronto 1, Ontario.

PFAUDLER PERMUTIT INC.

Wedge-Lock®

HANDLES INFILTRATION!



ROOT-TIGHT SEAL!

Patented Wedge-Lock Joints are bonded to Vitrified Clay Pipe—*at the factory*—to bring you the highest performance standards . . . the lowest installation costs.

One simple, easy operation and the joint's tightly sealed around the full pipe circumference . . . stays in continuous compression for the life of the pipe.

MINIMUM INFILTRATION!

When you specify Wedge-Lock, you reduce infiltration and resist root problems before they start . . . keep installation costs down . . . benefit from the guaranteed performance of the world's longest-lasting pipe.

Write to listed manufacturers for literature or an actual Wedge-Lock demonstration

Wedge-Lock CLAY PIPE

THE FACTORY-JOINTED CLAY PIPE AVAILABLE NATIONALLY FROM LOCAL MANUFACTURERS

Order Wedge-Lock from any of these Vitrified Clay Pipe Manufacturers:

Cannelton Sewer Pipe Company Cannelton, Ind.

The Clay City Pipe Company Uhrichsville, Ohio

The Evans Pipe Company Uhrichsville, Ohio

Graff-Kittanning Clay Products Worthington, Pa.

Larson Clay Pipe Company Detroit, Mich.

The Logan Clay Products Company Logan, Ohio

The Robinson Clay Product Company Akron, Ohio

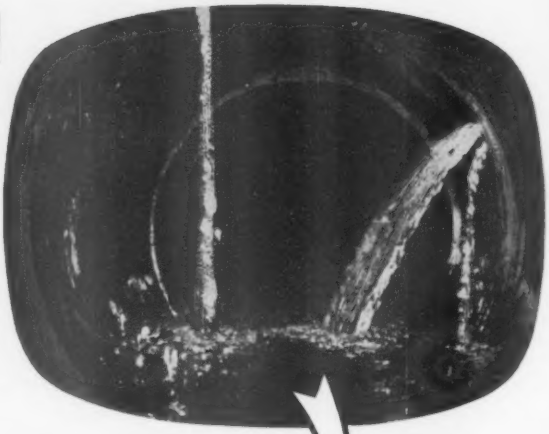
The Stillwater Clay Products Company Cleveland, Ohio

Superior Clay Corporation, Uhrichsville, Ohio

WLC-159-185-B

TV CRAWLS THRU SEWERS!

Dramatic new method locates trouble! No guess work! No costly tearing up sewer lines!



Remote monitor permits on the scene observation. The infiltration or exfiltration points are exactly located by pulling the TV camera through the main until damaged point appears on TV monitor.

The time-honored, and most expensive, method of repair is to calculate through weirs at strategic locations the general area of infiltration; then, to excavate and repair.

Rapid technological advances, employing the use of high pressure grouting and jetting systems, have relegated older methods into the limbo of antiquity.

Foremost in the technology of sewer repair is the utilization of closed circuit TV, making immediate and positive visual observation of repair possible.

Right: T.V. camera about to be inserted in sewer line.

Extreme Right: With source of infiltration pin pointed by T.V., pipes are jetted to position through water pressure and compressed air, one on each side and another just above the main.

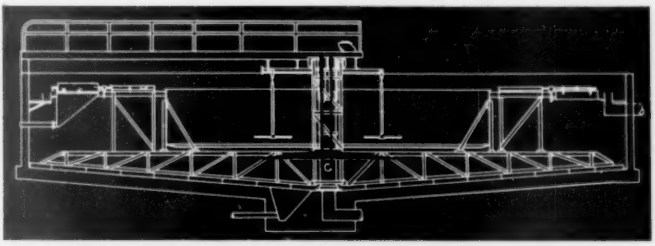
WRITE or PHONE
for further information and illustrated brochure

industrial pipe repair corp.

200 N. STONESTREET AVE., ROCKVILLE, MD.
PHONE POplar 2-6919

2100 N. DIXIE, FORT LAUDERDALE, FLA.
PHONE LOgan 4-4326

Another Eimco-Process design innovation . . .



Internal sludge recirculators, Non-Clog Diffusers and a sludge thickening deflector are exclusive features of the Type CA Oxidator.

EIMCO-PROCESS OXIDATOR®—WITH CONTROLLED INTERNAL SLUDGE RECIRCULATION—INCREASES SOLIDS AND BOD REMOVALS

The complete line of Eimco-Process Oxidators, Clarifiers and other sedimentation equipment is described in our new Bulletin SM-1005. We will be happy to send you a copy on request.

Developed and introduced by Eimco-Process, and with a number of exclusive features, the Oxidator combines aeration, flocculation and sedimentation in a single circular tank. When aeration and flocculation of the solids are provided prior to clarification, many finely divided and colloidal solids that could not be removed by conventional sedimentation are flocculated and collected with the sludge. The aeration keeps the influent fresh and, combined with controlled internal sludge recirculation, gives increased floccule size, minimizes scum formation, and gives increased suspended solids and BOD removals.

In this unique design, internal sludge recirculation is accomplished through airlifts with intakes below the special sludge pocket protection deflector. By placing the intakes in this protected heavy sludge zone and controlling each lift with a separate valve, optimum recirculation rates can be obtained.

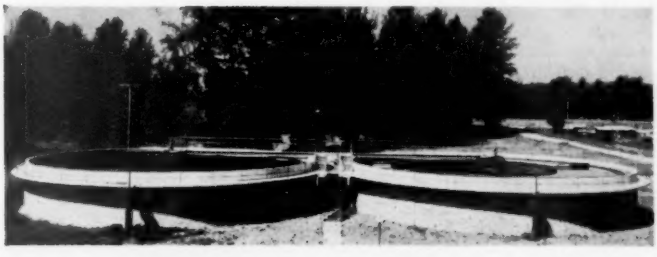
Gentle or intense aeration, adjustable sludge recirculation rates and controlled sludge thickening make the Oxidator the most flexible of all sedimentation equipment. Used alone, it can provide economical intermediate treatment; used with secondary equipment, it can substantially reduce total plant investment.

THE EIMCO CORPORATION
Salt Lake City, Utah

B - 394

PROCESS ENGINEERS, INC. *division*
420 Peninsular Avenue
San Mateo, Calif.

. . . another outstanding installation



Two 75 ft. dia. Type CA Oxidators, Puyallup, Washington. Consulting Engineers—Gray and Osborne, Yakima, Wash.

8" Transite Sewer Pipe being installed, Winchester, Mass.

James D. Halwarz, Superintendent of Water and Sewer Dept., Winchester, Mass., says . . .

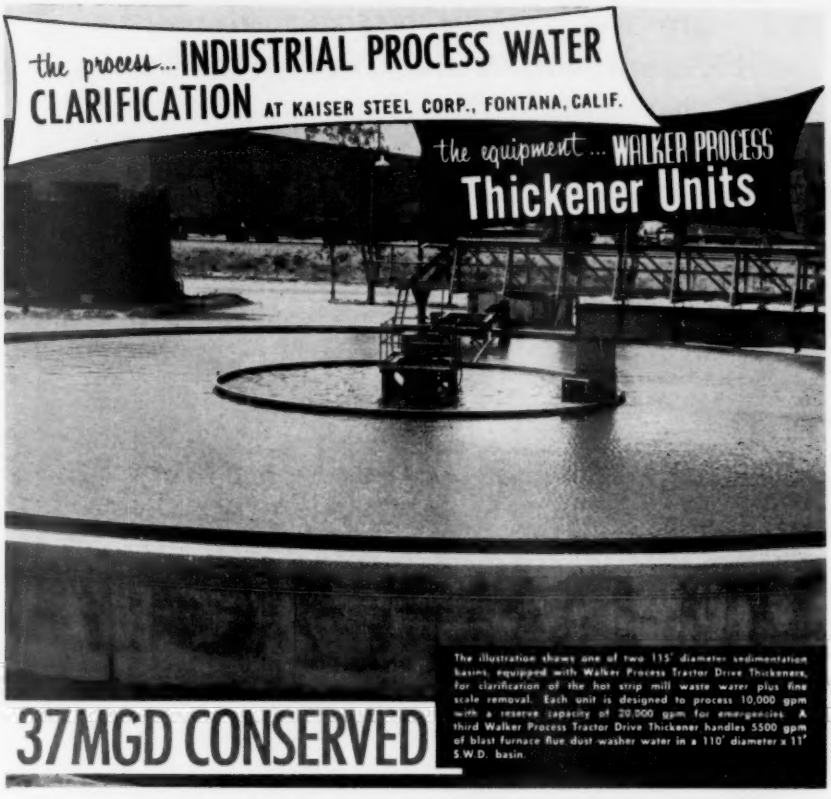
"Transite Sewer Pipe gives us the maintenance-free results we want . . . no root trouble, no infiltration, and no breakage in service."

"And because of its ease of handling and speed of installation, our final costs are less than with other materials," Mr. Halwarz continues. "We first started using Transite in 1935 to eliminate the cleaning of water mains. We liked it so well that less than a year later we started to use Transite Sewer Pipe. In over twenty years of using it, we have yet to clean or replace a single length of Transite Sewer Pipe. Transite is specified for both water and sewer mains in the town of Winchester."

Each year, in every part of the nation, we see significant increases in the use of Transite® Sewer Pipe. To find out why, send for the new Sewer Pipe data kit—containing flow rates, new Transite crushing strengths, and TR-165, the informative brochure on Transite Sewer Pipe, its application and installation. Write, today, to Johns-Manville, Box 14CM, New York 16, N. Y. In Canada, Port Credit, Ontario.

Transite Ring-Tite® Coupling—tight, lasting seal against roots and infiltration of ground water.

JOHNS-MANVILLE JOHNS-MANVILLE JM PRODUCTS


the process... INDUSTRIAL PROCESS WATER
CLARIFICATION AT KAISER STEEL CORP., FONTANA, CALIF.
the equipment... WALKER PROCESS
Thickener Units
37MGD CONSERVED
The illustration shows one of two 115' diameter sedimentation basins, equipped with Walker Process Tractor Drive Thickeners, for clarification of the hot strip mill waste water plus fine scale removal. Each unit is designed to process 10,000 gpm with a reserve capacity of 20,000 gpm for emergencies. A third Walker Process Tractor Drive Thickener handles 5500 gpm of blast furnace flue dust washer water in a 110' diameter x 11' S.W.D. basin.

Waste water treatment at Kaiser Steel Corporation's Fontana, California Works includes facilities for handling blast furnace flue dust washer water and hot strip mill process water. A combined total of 37 MGD indicates the importance of waste water treatment—from a conservation standpoint as well as operating economy.

Heavy fines and particles, encountered in steel mill wastes, require equipment designed to move literally tons of abrasive sludge with as little maintenance as possible. Walker Process Tractor Drive Thickeners especially suit these conditions. The drive at the periphery of the basin utilizes the bridge as a lever to exert high rotational force with a minimum of gear reducer effort.

This feature also permits the use of simpler, more accessible gear reducers which simplify maintenance and adds years to the service life of the unit.

In addition to Tractor Drive Thickeners, Walker Process manufactures sludge collector units for all types and sizes of applications—circular, rugged, center drive units, either pier or bridge supported and rectangular mechanisms.

Write for information on equipment for the treatment of municipal water and sewage and industrial liquids.

WALKER PROCESS

WALKER PROCESS EQUIPMENT INC.
FACTORY • ENGINEERING OFFICES • LABORATORIES
AURORA, ILLINOIS

Attractive, Corrosion-Resistant Glazed-Tile Effluent and Water Treatment Tanks

Exacting Design — Meticulous Workmanship

As the final step of construction, Stebbins workmen carefully wash down the exterior of the tanks with acid.

In this view of tank floors under construction, note the clean, smooth joints – the mark of good workmanship. Note the variety of tile shapes. Horizontal and vertical steel reinforcing is shown in the walls which will be solidly filled with concrete as work progresses.

Complete Service — Design, Installation, Maintenance

WRITE FOR BULLETIN AET-59

SEMCO

STEBBINS Engineering and Manufacturing Company

WATERTOWN, N. Y. • PENSACOLA, FLORIDA

STEBBINS ENGINEERING CORP. — 1504 TOWER BLDG., SEATTLE, WASH.

CANADIAN STEBBINS ENGINEERING & MANUFACTURING CO., LTD.

TOWN OF MOUNT ROYAL, MONTREAL 9 • 12 MERCHANT EXCHANGE BLDG., VANCOUVER

SINCE 1884

Specialists in Design, Installation and Servicing of Linings and Tile Tanks

Year/1939

New steels are born at Armco

Problem:

Carry sewage under an irrigation canal without infiltration.

Solution:

Install Armco Corrugated Metal Pipe. The tight joints stopped infiltration.

Here is the sewer after 20 years' service

This 36-inch Armco Corrugated Metal Pipe is shown after 20 years of carrying fast-moving corrosive sewage under an irrigation canal in Pueblo, Colorado. There is still no measurable infiltration. Sewer is good for many more years of service.

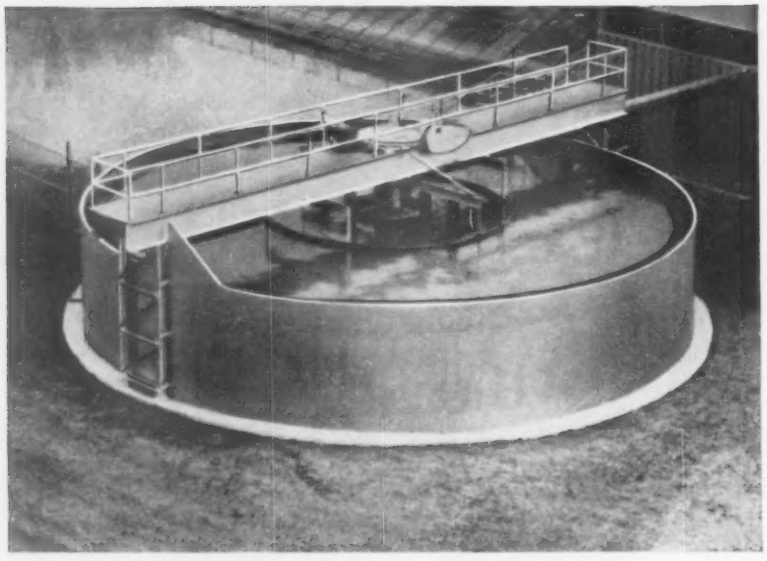
Write us for catalog

For complete details on Armco Sewer Structures, write Armco Drainage & Metal Products, Inc., 6899 Curtis Street, Middletown, Ohio.

ARMCO DRAINAGE & METAL PRODUCTS

Subsidiary of ARMCO STEEL CORPORATION

OTHER SUBSIDIARIES AND DIVISIONS: Armco Division • Sheffield Division • The National Supply Company • The Armco International Corporation • Union Wire Rope Corporation Southwest Steel Products



how Scovill Manufacturing Co. found the answer to

TREATMENT OF TUBE MILLS PICKLING WASTES

Dorrco Clariflocculator carries out dual treatment operation in a single tank

Metal pickling wastes from the Scovill Manufacturing Company's brass and copper tube mills at New Milford, Connecticut average 400 gallons per minute of rinse solution.

Removal of zinc and copper carbonates and return of the clarified liquor for re-use as rinse water involves a flocculating operation to facilitate rapid settling of the finely divided particles and dissolved salts. The dual operations of flocculation and clarification are carried out in a Dorrco Clariflocculator—a combination unit with two compartments within a single tank.

The Dorrco Clariflocculator is ideally suited to the treatment of wastes involving copper, zinc, aluminum or nickel salts and is adaptable to a wide range of feed volumes and concentrations. Dorr-Oliver engineers have a wealth of experience to bring to the solution of your waste treatment problems. We would welcome the opportunity of talking with you or your consultant. Dorr-Oliver Incorporated, Stamford, Conn.

DORR-OLIVER
INCORPORATED
WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT
STAMFORD • CONNECTICUT • U.S.A.

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1958 Literature Review

A REVIEW OF THE LITERATURE OF 1958 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By H. Heukelekian, *Chairman*, R. Manganelli, *Vice-Chairman*, H. Amberg, E. J. Berg, H. F. Clark, C. H. Connell, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, I. Gellman, H. G. Harding, R. D. Hoak, R. S. Ingols, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, H. G. Luley, P. H. McGauhey, W. A. Moore, R. Porges, E. R. Roth, A. J. Steffen, C. Straub, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, E. Weisberg, and R. L. Woodward

Research Committee, Federation of Sewage and Industrial Wastes Associations

This second of three sections of the Literature Review covers industrial wastes, including those of a radioactive nature. Owing to the extensive coverage, the industrial wastes section on radioactivity is referenced separately from the discussion of other industrial wastes.

The first section, dealing with analytical methods and sewage, was published in the May 1959 issue of This Journal. The third section, on water pollution, will be published in the July 1959 issue of This Journal.

INDUSTRIAL WASTES

Food Processing Wastes

Canning

An interesting dissertation by Barnes and Weinberger (16) reveals that the concentration and volume of pickle packing wastes have been reduced substantially by surveys tracing the source of pollution and thereby providing a means for control of the pollution potential. Elimination of wastes resulting from drip, dump, transfer, and spill losses, by changes in routines and equipment, has reduced the BOD as much as 64 per cent. The segregation and storage of potent liquors for release during high stream flow further reduced the BOD by 80 per cent. By such reductions in BOD without treatment, appreciable savings in treatment costs are effected. Additional savings are available in recoverable material such as sugars and liquors. The principals involved herein could be applied to other food processing wastes as well as to many other industries.

Ingols (77) presented a review of the newer methods for treating food processing wastes. Brief descriptions are given of the treatment facilities at the Green Giant Company, Seabrook Farms, and at another tomato canning

operation where spray irrigation is used. The discussion covers limitations in the use of spray irrigation in the disposal of citrus and pea wastes. Salable by-products from the citrus industry in the form of citrus molasses, feed yeast, and alcohol are also discussed, as is silage from bean and pea canning operations. The paper covers the advantages of reducing pollution loading at its source by improvement in processes and the mixing of effluent with the entire dilution water. Factors involved in the selection of a plant site for canning operations are presented with an outlook toward low waste treatment costs.

Data was obtained by Lunsford and Dunstan (97) to indicate that pea blancher waste is amenable to stabilization by anaerobic digestion at both mesophilic and thermophilic temperatures.

An interesting approach to the control of fly breeding in food processing waste lagoons is presented by McCoy (103). The covering of the waste lagoons with a film of black polyethylene is credited with accomplishing successful suppression of fly breeding at the waste lagoon site. The cost of this method installed is approximately 8¢ per sq ft of lagoon area.

The problem of handling solid waste from canning operations has originated a study reported by Canham (26) wherein the inclusion of solids with liquid waste for disposal by spray irrigation was investigated. The report included mechanical problems encountered, the effect of comminuted solids on the soil and on the cover crop, and the costs involved. The study was conducted at a midwestern pea processing plant but the author points out that products other than peas might involve problems not encountered in these tests and recommends further study with each product. The study reveals that this method of disposal of solids is feasible at lower costs than the usual separation and disposal.

Brooke and Capel (20) reported on an economic study of the disposal of solid tomato waste. A comparison of disposal cost by dehydration, county pit disposal, field disposal, and industry pit disposal is presented for Dade County, Florida.

Previous laboratory and pilot-plant work by Dougherty and McNary (42) on vitamin content of activated citrus sludge has been continued to obtain the maximum vitamin production and further results of vitamin content of the sludge in a properly designed activated sludge system operating under normal conditions.

Pilot-plant work on the treatment of citrus wastewater by the activated sludge process became overloaded to the extent that the resulting rise in temperature seriously harmed the microorganisms involved. Dougherty and McNary (43) present the results of experiments to find the effect of increased temperature on an activated sludge culture without having overloaded conditions.

Interesting information is presented by Caster (28), Kraus (88), and Van Kleeck (152) on combined municipal-industrial waste treatment that provides background thinking for the food processing industry.

The problem of finding methods to treat wastewater of the sugar and starch manufacturer, distiller, fruit and vegetable preserver, and flax retter, both economically and technically acceptable, is discussed by Colas (32). The problem is discussed with reference to the situation in France. The difficulties brought out are the seasonal operation, the fact that the season may coincide with the time of high or low water, and the situation that there may be coincidence with the fishery season.

Lefebvre and Dickinson (93) review published information on the treatment of waste from the fruit and vegetable canning industry in Belgium and England. The article lists different techniques available and discusses the

activities in reference to processing wastes.

Sugar

The pollution of surface waters by food industry wastewaters is discussed by Mansson (99). Examples used are mainly from the sugar industry in Sweden. The reduction of water consumption and wastewater output is the result of the reclaiming of wastewater and process improvements applied.

Rao, Skukla, and Kapur (125) have measured volumes of effluents from various processes in a sugar factory and have analyzed the effluents for the quantity of dissolved and suspended solids BOD and odor. They describe a successful pilot plant in which filtered effluent is treated with lime, coagulated, and the clear supernatant liquor is decanted after sedimentation. The estimates of cost for such treatment facilities are considered high.

Dairy Wastes

The Eastern Regional Laboratory of the United States Department of Agriculture has continued research on the aeration of whey wastes. Jasewicz and Porges (81) studied the laboratory aeration of dilute whey in two systems, one with and the other without supplementation with nitrogen (14.6 mg/l N from NH_4OH). Each system started with 2,000 mg/l washed sludge solids from a skim milk aeration system plus 1,000 mg/l whey solids in 12 liters. Eight liters of supernatant were replaced daily with 8 liters containing 12 g whey solids. In spite of the favorable temperature (84 to 90°F) for endogenous respiration and excess air (18 l/min or about 23.5 cfm/lb COD, as well as the removal of samples) the sludge solids increased in 96 days to about 4,650 mg/l in the system with added N and to 5,070 mg/l in the system without added N. At this time both systems still gave complete whey removal to the sludge and the sludge with added N gave more rapid oxidation of the intracellular material. This study confirms industrial experience that modified activated sludge treatment of dairy wastes containing substantial amounts of whey, produces a satisfactory effluent and a buildup of poorly settling sludge which resists auto digestion by endogenous respiration in spite of nitrogen supplementation. In a later paper from the same laboratories, Wasserman, Hopkins, and Porges (156) looking for saleable products which might utilize part of the nine billion pounds per year of cheese whey now going to waste, studied the conditions necessary for the optimum growth of a yeast, *S. fragilis*, on whey. Yeast is used in animal feeds. The addition of 0.5 per cent $(NH_4)_2SO_4$, 0.5 per cent K_2HPO_4, and 0.1 per cent yeast extract were found to be necessary for good growth. Initial adjustment of the whey medium to pH 5.0 to 5.7 gave maximum growth. A high inoculum (about two billion yeast cells per milliliter) reduced the growth period to three to four hours. Nonsterile whey gave as good growth as sterile whey.

As reported at length in last year's review, when at all practical, the preferred method for dairy waste disposal is land irrigation. Several additional papers have appeared with favorable reports from Germany, New Zealand, and Sweden, which, however, contain no new facts. Consequently, they are listed below as "additional references."

Additional favorable reports have appeared on the modified activated sludge treatment units tested in Germany and discussed in the 1956 review. According to an anonymous (9) report the "Aquapura" now has a small plant in operation at Loccum (Germany) handling 5,300 gpd of wastewater from a cheese plant which is handling 30,000 lb/day of milk in a 6-hr operation per day. The treatment unit has an aerated storage compartment of 5,300-gal capacity and an aeration compartment of the same size. It uses a Kessner type

rotating brush for aeration. The waste is pumped at the rate of 26 gpm of which 5 gpm goes to the aeration tank while the rest goes back to the storage compartment. The organic load averages about 53 lb/day of 20-day BOD, which presumably might be equivalent to 37 lb of 5-day BOD. There is a circular clarifier with four hours of retention. Nothing is said about rate of sludge return, control of sludge concentration, or disposal of excess sludge.

Kannemeyer (82) reports on an Aero-Accelator installation in Meerdorf (Germany) in 1957. It handles 12,000 to 15,000 gpd of wastewater containing 197 to 344 mg/l of 5-day BOD. The BOD loading is 20 to 44 lb/day. Final effluents show 15 to 33 mg/l BOD. Power consumption is 40 kwhr/day. The rate of flow through the unit is 33 gpm. The waste comes from a fluid milk plant which takes in an average of 25,000 lb/day milk, half of which goes into fluid bulk milk and one-tenth into bottled milk. The rest is separated and the cream made into butter. The skim is partly returned to the farmers with the buttermilk and the whey. Most of the skim goes into the usual line of by-products. The milk plant and the treatment unit operate only during the day, but provision has been made for keeping the sludge fresh by some aeration and recirculation at night. The unit actually provides for 100 per cent sludge recirculation, but the sludge blanket level in the clarifier compartment (which surrounds the aeration compartment) is kept constant by means of a photo cell which will start and stop the sludge discharge pump automatically. The sludge is pumped to a tank. Sludge quantities and the tank sizes are not given. Probably the tank is an anaerobic digester. If so, a report on its performance would be of great interest.

At a two-stage, high-rate trickling filter plant previously described by Zack in 1956 for treating milk processing plant wastes, overloading caused a serious upset in operation. Klein (85) describes operating experience with this plant and the changes made so as to include sanitary wastes and to handle peak organic loads of more than double the design BOD load. Removal of excess sludge by tank truck and heating the digester to 85° to 90°F have established normal digester operation. At time of peak loading, analytical results showed a reduction from influent to effluent of 83 per cent in turbidity, 87 per cent in total solids, and 89 per cent in 5-day BOD.

Additional References

Biernath, D., "New Viewpoints on the Treatment of Land with Dairy Effluents." *Fette, Seifen, Anstrichmittel* (Germany), **60**, 317 (1958); *Dairy Sci. Abs.* (Brit.), **20**, 923 (1958).

Csiszar, V., "The Treatment of Waste Water of Slaughter Houses and Dairies." *Magyar Allatorvosok Lapja* (Hungary), **10**, 42 (1955); *Chem. Abs.*, **52**, 20743 (1958).

Flinspach, H., "Waste Water Purification in Dairies by Irrigation." *Molkerei-Ztg.* (Germany), **12**, 912 (1958).

Genin, G., "Treatment of Waste Residues of the Dairy." *Lait* (France), **38**, 383 (1958); *Chem. Abs.*, **52**, 20720 (1958).

Kountz, R. R., "Aerobic Digestion of Dairy Wastes." *Proc. 5th Southern Munic. Ind. Waste Conf.*, 238 (1956).

Magnusson, F., "Purification of Dairy Waste Waters." *Svensk Mejeritidn.* (Sweden), **50**, 275 (1958); *Dairy Sci. Abs.* (Brit.), **20**, 648 (1958).

Magnusson, F., "Treatment of Dairy Waste by Spray Irrigation." *Svensk Mejeritidn.* (Sweden), **50**, 261 (1958); *Dairy Sci. Abs.* (Brit.), **20**, 648 (1958).

McDowall, F. H., "Dairy Wastes: Disposal by Spray Irrigation on Pasture Land." *Dairy Eng.* (Brit.), **75**, 251 (1958); *Dairy Sci. Abs.* (Brit.), **20**, 923 (1958).

Porges, N., "Dairy Waste Disposal by Balanced Biochemical Bio-oxidation." *Dairy Eng.* (Brit.), **75**, 255 and 294 (1958).

Porges, N., "Practical Application of Laboratory Data to Dairy Waste Treatment." *Food Tech.*, **12**, 78 (1958).

Prasse, P. E., "Spraying of Dairy Wastes." *Molkerei- u. Kaserei-Ztg.* (Germany), **9**, 93 (1958).

Quest, H., "Principles of the Purification of Dairy Effluent." *Molkerei- u. Kaserei-Ztg.* (Germany), **9**, 750 (1958).

Schulz-Falkenhain, H., "The Costs of Waste Water (Disposal) in Dairy Plants." *Molkerei- u. Kaserei-Ztg.* (Germany), **9**, 799 (1958).

Meat Packing and Poultry Processing Wastes

Practical measures for in-plant waste prevention and conservation in meat packing plants were outlined by Aikins (2). Data on the initial operation of a modified anaerobic digestion type plant treating packing plant wastes, reported by Steffen (143), include comments on break-in procedures and plans for future research. During the fourth month of operation, the plant was handling a 40 per cent overload in BOD with over 92 per cent BOD removal. A unique feature of the plant is the removal of residual gases from the digester effluent by vacuum degasification, to produce a non-rising sludge which is returned from the separator (or clarifier) to the digester to supply seed for the digestion process.

Data on poultry processing wastes by Kaplovsky (83) are based on studies of four Delaware plants. He reports that approximately 95 per cent of the pollutional load originates in cleaning of feeder stations and poultry batteries. The trend toward direct processing, without holding poultry in feeding stations, is thus reducing unit loads and necessitates a revision of past concepts of the pollutional effect of poultry wastes. The economics of by-product recovery in the Delaware area are also discussed.

A discussion by Roberts (129) of combined treatment of poultry and domestic wastes at Gainesville, Georgia, points up the importance of interception of solids by mechanical screening at the source. Digestion of the solids was achieved by adequate recirculation of sludge and by resting one digester at a time. The author recommends a cutter type grinder for screenings and the use of the newer full-flow type sludge pumps in preference to plunger pumps.

Additional Reference

Csiszar, V., "The Treatment of Waste Water of Slaughter Houses and Dairies." *Magyar Allatorvosok Lapja* (Hungary), **10**, 42 (1955); *Chem Abs.*, **52**, 20743 (1958).

Fermentation, Chemical, and Pharmaceutical Wastes

Vaughn *et al.* (153) discussed the effect of winery stillage pretreatment on the resultant treatment efficiency of a domestic sewage treatment plant receiving these wastes. Of three detartration methods studied, including cold throw, centrifuging, and hot throw, the latter produced optimum BOD reduction. BOD of combined winery wastes and sanitary sewage was reduced from 2,100 to 420 mg/l by means of calcium chloride addition and lime neutralization. A trickling filter plant with 3 mgd design capacity receiving 50,000 gpd detartrated stillage and 1.5 mgd sanitary sewage then produced 90 per cent BOD reduction as compared to 54 per cent prior to pretreatment.

Meinhold and Arnold (104) described the operation of a submerged combustion unit used to concentrate 2,400 lb/hr of boron-caustic wastes from high energy fuel production. A 2-mil Btu/hr gas-fired burner evaporated 1,900 lb/hr of steam, leaving 500 lb/hr of concentrate containing 50 per cent caustic for ultimate disposal by hauling. Nagy (114) reported on an incinerator installation designed for disposal of 2,000 gpd of benzene acid sludges containing from 30 to 75 per cent sulfuric acid resulting from benzene product purification reactions, along with 7,000 lb/day of solid combustible residues. Incinerator site selection factors and incinerator design are detailed as are construction and operating costs.

Hedgepeth *et al.* (71) described the extensive preliminary studies designed to develop suitable treatment proce-

dures for a new acrylic fiber production facility, including disposal methods for thiocyanate wastes. Treatment will include neutralization, equalization, skimming and sedimentation, and lagooning, followed by offshore diffusion. Remy and Lauria (127) reviewed preliminary studies, design, and operation of facilities for disposal of wastes from nylon production. Effluent from production of adipic acid via cyclohexane oxidation contains quantities of succinic, adipic, glutaric, and acetic acids, adiponitrile, hexamethylene imine, acetone, methyl ethyl ketone, and cyclohexane. Treatment facilities designed to prevent reduction of receiving water dissolved oxygen below 5 mg/l include submerged combustion for 125 gpm of strong waste flow, equalization, neutralization with ammonia, nutrient addition, and high-rate activated sludge treatment at 1.2 lb BOD per lb sludge carried, followed by sedimentation and controlled effluent release. Greene (61) described experimental work on trickling filter treatment of rayon fiber wastes mixed with sanitary sewage in volumes two and one-half times that of the rayon effluent.

Tully (147) discussed the treatment of acidic wastes from production of various silicone products. Upflow limestone neutralization with recirculation of settled effluent is employed, following sedimentation for removal of silicone gel, for wastes containing one per cent hydrochloric and sulfuric acids. Cost data are presented indicating an investment of $35,000 for a facility capable of handling 750 gpm of 1 per cent acid wastes. Total operating costs are 49¢ per ton of 1 per cent acid waste. Faust and Orford (47) reported on research studies of sulfuric acid waste neutralization using native gypsum and recycled sludge to improve sedimentation properties of sludges resulting from lime neutralization. Use of native gypsum seed caused reduced sludge volumes by a factor of 4 to 7 times. Sludge recycled 10 to 15 times, originally seeded with native gypsum, similarly reduced sludge volumes by a factor of 3 to 5 times. Recycling of calcium sulfate sludge without benefit of initial seeding was far less effective. Microscopic evidence was presented to show that deposition on properly-oriented introduced crystal surfaces was responsible for the improvement.

Heller *et al.* (72) reviewed the available methods for dephenolizing various process streams. Processes reviewed include steam stripping and solvent extraction using counter-current procedures. The latter include benzene and light oils, tricresyl phosphate, low boiling aliphatic esters, and light aromatics. Equipment used includes centrifugal contactors and mechanically agitated columns. Process selection factors are reviewed and detailed data are presented for two specific installations employing steam stripping and solvent extraction. Kirchgessner (84) described phenol recovery at an integrated phenolic resin plant. The original installation employing counter-current benzene extraction was frequently fouled by phenolic resin deposition and generally produced effluents exceeding 1,000 mg/l phenol. Use of isopropyl ether with ether recovery from the water layer by steam stripping has proven preferable to benzene, although column fouling still remains a problem. The new method produces an effluent of 200 mg/l phenol from an influent of 5 per cent phenol.

Additional References

Harkness, N., and Jenkins, S. H., "Chemical and Biological Oxidation of Styrene and Isoprene." *Jour. and Proc., Inst. Sew. Purif.*, Part 2, p. 216 (1958).

Haywood, R. W., Jr., "Basic Data for Chemical Waste Disposal." THIS JOURNAL, **30**, 9, 1156 (Sept. 1958).

Mauriello, C. G., "Operating Problems of Industrial Wastes Treatment Plants. VI. Biological and Pharmaceutical Wastes." THIS JOURNAL, **30**, 11, 1397 (Nov. 1958).

Paradiso, S., and Howe, R. H. L., "Spent Antibiotic Broth Treatment at Eli Lilly Co." *Ind. Wastes*, **3**, 101 (1958).

Reid, F., "Two Major Industries Cut Their Waste Problems by Self Analysis." *Wastes Eng.*, **29**, 190 (1958).

Coal Wastes

Raleigh (124) predicts that acid mine-drainage controls will be introduced in the Ohio River Valley. Punitive legislation can be avoided only if there is an industry-wide effort to curb all pollutional wastes. A producers' committee is proposed to carry out a voluntary control program.

Pennsylvania (6) has had notable success in controlling acid mine water; chemical inhibitors are eschewed. The program has been based on control of physical features and methods of operating active coal pits with the objective of keeping water out of pits and promptly pumping away any water that enters. Some of the effective measures are: (a) using diversion ditches to keep water out of strip mines, (b) collecting and channelling ground water away from the workings, (c) avoiding stripping across stream channels, (d) backfilling pits to decrease the time sulfuritic material is exposed to air and moisture, and (e) preventing seepage into sulfur-bearing waste by segregating gob and sealing it off with an impervious cover. Similar methods are used to control acid water from active deep mines, but there is no solution in sight for the problem of acid water flowing from abandoned mines.

It is reported (7) that a plant under construction near Duisburg in the Ruhr District of Germany will convert waste sludge into 150,000 tons of coal dust per year. The dust will contain about 46 per cent nonvolatiles and 1 to 2 per cent water. It will be used primarily by power plants with which long-term contracts have been signed. The process is covered by pending patents and details are not yet available.

Ferro coke, a carbonized blend of coal and blast furnace flue dust, provides a practical way to use flue dust without sintering. Mitchell and Sediachek (111) state that the dust is mixed with 80 per cent of high volatile coal and coked in conventional ovens for about 22 hr. The coke has high strength and, as blast furnace burden, it may be valued at the price of a unit of ore plus credit for reduction of its contained iron oxide. The process is in commercial operation.

There exists considerable disagreement over the relative roles of chemical and bacterial oxidation of sulfuritic material. Bryner and Jameson (23) report the isolation and characterization of two chemosynthetic autotrophic bacteria from the leaching streams in Bingham Canyon, Utah. One of the organisms is able to oxidize free sulfur, ferrous iron, iron pyrites, molybdenite, and several copper sulfide minerals; it is very similar to *Thiobacillus ferrooxidans*. The other organism oxidizes free sulfur but not sulfide minerals; it is similar to *Thiobacillus thiooxidans*.

By-Product Coke Wastes

Drabek (44) reported confirmation of laboratory work by 15 months of full-scale trials wherein water containing 843 to 951 mg/l monohydric and 353 to 392 mg/l dihydric phenols was fed at 2 cu m/day to a slag heap with a volume of 120 cu m and a height of 3 m. Analysis over the first six months showed no phenols in the filtered water. In the remaining nine months the concentration ranged from 11.7 to 172 mg/l with no regular increase. The phenols absorbed during the trial amounted to 14 kg/ton of slag. In a later paper (45) the author reviews various methods for recovery or destruction of phenols by adsorption, ion exchange, and coke quenching.

A method for treating gas works effluents was patented by Davies and Cooper (38). Retort house liquor and hot liquors from condensers and gas detarrers are stripped of free ammonia and dephenolated with butyl acetate or methyl isobutyl ketone. They are then either run to waste or concentrated

for recovery of ammonium chloride. The remaining liquors, including final cooler liquors which contain mainly thiosulfates and thiocyanates with a little ammonium chloride, are steam-distilled to recover ammoniacal liquor. Any phenols can be removed by extraction with benzol before distillation. The liquors are concentrated by evaporation, ammonium chloride is separated if desired, and the concentrate is rendered harmless by treatment with nitric or sulfuric acid. The aqueous distillate is used as boiler feed, and the unwanted polyhydric phenols and noxious liquors are destroyed in a coke-burning furnace.

It was reported by Hall (65) that treatment of ammoniacal liquor with ozonized air destroys phenols, thiosulfate, thiocyanate, cyanides, and sulfides, provided the pH is controlled. The oxygen absorption value is reduced 75 to 80 per cent; further reduction does not occur because the decomposition products are not affected by ozone. The ozone to phenol ratio required to reduce the phenol content below 1 mg/l ranges from 0.7 to 2.7 for different coke works. The oxygen absorption value can be reduced if the liquor is treated biologically or by froth flotation before ozonation. The process is said to be economical. Abson and Todhunter (1) discussed recovery of phenols from coke works effluents in detail under three headings: distillation and absorption of the vapors, direct absorption, and extraction with solvents. Chemical oxidation with ozone, nitrous and nitric acids, or chlorine is often favored because the decomposition products are generally innocuous.

Phenol recovery processes were analyzed by Heller, Clarke, and Reiter (72). They point out that a steam-stripping unit, using tower intervals with low sensitivity to fouling, can be used for dephenolization of liquors with sharp variations in specific gravity, temperature, separable oils, and suspended solids. A steam-stripper with trays, operating at 45 psi, has been satisfactorily handling a complex and varying waste stream. On the other hand, solvent extraction offers a number of advantages over steam-stripping where the physical characteristics of phenolic wastewaters vary only slightly. Salvadori and Gignes (133) described a scheme for continuous fractionation of phenolic oils and coal tar hydrocarbons based upon separation of the azeotropes formed when a mixture of oil, water, and ethylene glycol is rectified.

Additional References

Jenkins, S. H., "Some Recent Developments in Treating Trade Wastes, Including Gas Works Effluents." *Jour. and Proc., Inst. Sew. Purif.*, Part 2, p. 184 (1957); *Pub. Health Eng. Abs.*, **38**, 4, 40 (1958).

Savage, A. P., "Solving Waste Problems of a Large Chemical Type Coke Plant by Co-operative Effort." *Blast Furnace Steel Plant*, **46**, 705 (1958).

Petroleum Processing Wastes

Studies continue on persistence of oily matter in streams and effects of such compounds and degradation products. A considerable number of waste control installations are reported by the petroleum industry, including four-stage treatment at two new refineries.

Observations on persistence and significance of refinery wastes in streams are summarized by Ludzack, Middleton, and Ettinger (95). Emulsion break and sedimentation occurred much more rapidly in actual stream studies than in the laboratory. Deposition of oily, flocculent, biological solids and silt is pointed out as forming a reservoir of waste products. Oily matter and degradation products are returned to the flowing stream during periods of high flow and gasification. Carbon filter, chromatographic, and infrared techniques are being combined to follow the course of oily wastes in streams. Biochemical degradation products are designated a "new dimension" in stream pollution by Bogan (17). Find-

ings on degradation of a number of types of compounds indicate that BOD values for a number of substances may be related to degradation of only a portion of the original molecule. Effect of biochemical end products then becomes an important question. Bogan concludes that organic stream pollutants generally cannot be evaluated adequately in terms of BOD or COD alone. Hydrocarbon assimilation by microorganisms is reviewed in a Russian article by Shturm (139). Products of decomposition are given.

Experiences in lagoon disposal of wastes are related by Hull (76) and Irwin (79). Extensive treatment facilities are described for two recently completed refineries (35) (118). In addition to "in-plant" controls, refinery effluents are sequentially treated by gravity oil-water separation, chemical flocculation, activated sludge, biological oxidation, and lagooning.

Deep sea disposal of petrochemical wastes is described by Hood, Stevenson, and Jeffrey (75). Effect on organisms was studied both in the laboratory and at disposal sites.

Developments in treating methods include studies on reducing sludge volumes. Sludge volumes from chemical flocculation of oily matter are markedly reduced by practices related by McCord and Enquist (102). An 80 per cent reduction in sludges is accomplished by continuously aerating, chlorinating, and recirculating sludge. Treatment of boiler blowdown water to reduce alkalinity by underwater combustion is described (60). Another new treatment system is described (10) and is said to be satisfactory.

Thermal pollution of streams is pointed out as an important consideration by Moore (112). Use of air coolers, together with a discussion of other pollution control measures in the industry, is related by Brady (19). Extensive use of cooling towers to reduce heat load and water usage is given by Merman and Roth (106).

A new manual on disposal of refinery wastes covers up-to-date technology on sources, effects, and treatment of chemical wastes (4).

Additional References

Andrews, T. F., "The Value of Year-Round Limnological Studies to Industry." Third Western Petroleum Refiners Assn. Water Disposal and Stream Pollution Conf., Wichita, Kans. (Oct. 1–2, 1958).

Anon., "How to Cope with a Pollution Problem." *Chem. Eng.*, **65**, 129 (July 14, 1958).

Anon., "Esso's Antipollution Control." *Chem. Week*, **82**, 47 (May 10, 1958).

Anon., "The New Collection and Treating Plant for Oil Residues at Hamburg Harbor." *Erdol u. Kohle* (Germany), **11**, 576 (Aug. 1958).

Anon., "Sun, Fluor Offer New Process." *Oil Gas Jour.*, **56**, 62 (Feb. 3, 1958).

Anon., "Biological Treatment of Phenolic Effluent." *Petroleum* (Brit.), **21**, 233 (1958).

Anon., "Sinclair Refining Co. Plans Separator Basin for Reducing Refinery Pollutant Discharge." *Petroleum Week*, **6**, 36 (Jan. 10, 1958).

Anon., "Shell Chemical Gets New Waste Disposal Unit at Houston." *Petroleum Week*, **7**, 34 (Sept. 12, 1958).

Anon., "Effect of Organic Discharges on the Level of Oxygen in a Stream." *Water Poll. Abs.* (Brit.), **31**, 359 (Oct. 1958).

Anon., "Foul Condensate Treatment and Disposal." THIS JOURNAL, **30**, 2, 185 (Feb. 1958).

Burroughs, L. C., "Control of Pollution in Shell's Refineries." THIS JOURNAL, **30**, 1, 57 (Jan. 1958).

Dorris, T. C., Gould, W., and Jenkins, C. R., "Toxicity Bioassay of Oil Refinery Effluents in Oklahoma." Third Western Petroleum Refiners Assn. Water Disposal and Stream Pollution Conf., Wichita, Kans. (Oct. 1–2, 1958).

Gummels, H., "Treatment of Aircraft Washing Waters." *Gesundh. Ing.*, **79**, 16 (1958); *Water Poll. Abs.* (Brit.), **31**, 10, 355 (Oct. 1958).

Harris, T. R., "Disposal of Refinery Waste Sulfuric Acid." *Ind. Eng. Chem.*, **50**, 81A (1958).

Heard, D. B., "Experiences with Plant Scale Flotation Installations." Third Western Petroleum Refiners Assn. Water Disposal and Stream Pollution Conf., Wichita, Kans. (Oct. 1–2, 1958).

Hull, C. D., "One Refiner's Approach to Disposal Problems." Third Western Petroleum Refiners Assn. Water Disposal and Stream Pollution Conf., Wichita, Kans. (Oct. 1–2, 1958).

Katz, W. J., "Treat Wastes with Dissolved Air." *Petroleum Refiner*, **37**, 211 (1958).
Knorr, M., "Mineral Oils and Their Products in Soil and Ground Water." *Water* (Netherlands), **41**, 247 (1958); *Water Poll. Abs.* (Brit.), **31**, 36 (Jan. 1958).
Luchter, A., "Biological Method of Purification of Cresol Effluents from Refineries." *Bull. Polish Inst. Petroleum*, **7**, 1 (1957).
Metzler, D. W., "Water Quality Goals for Kansas Streams." Third Western Petroleum Refiners Assn. Water Disposal and Stream Pollution Conf., Wichita, Kans. (Oct. 1-2, 1958).
Ray, F. E., "Operating Problems of Industrial Wastes Treatment Plants. IV. Oil Refining Wastes." THIS JOURNAL, **30**, 11, 1379 (Nov. 1958).
Vrablik, E. R., "An Evaluation of Circular Gravity-Type Separation and Dissolved-Air Flotation for Treating Oil Refinery Waste Water." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 73 (1957).
Zimmerman, F. J., "New Waste Disposal Process." *Chem. Eng.*, **65**, 117 (Aug. 25, 1958).

Pickling and Acid Wastes

Disposal of pickle liquor from a small batch operation with a crystallization-regeneration process was described by Lang (90). Three times weekly a 400-gal volume of liquor containing 25 per cent ferrous sulfate is pumped from a 1,200-gal batch pickler to a cypress crystallization vat equipped with a cooling coil of 2-in. polyethylene pipe. Make-up acid is added to the vat and the mixture is cooled to 70°F over a period of 1 to 2 days. The mother liquor is returned to the pickler and the copperas is hauled to a dump. The installed cost of the recovery plant was $2,000. Labergere (89) noted that batch pickling can be continued before regeneration by crystallization of copperas, until the iron content reaches 130 to 140 g/l. For continuous pickling, however, the pickling rate becomes too slow if the iron content exceeds about 72 g/l before regeneration. Atwood and Hodge (14) described a process for regeneration of spent pickle liquor by recovery of ferrous sulfate monohydrate. The paper covers technical and economic factors.

Sorensen and Douty (141) reported that concentrated calcium-base spent sulfite liquor can be burned in a refractory-lined furnace without a secondary fuel. The experimental furnace was a horizontal cylinder lined with firebrick. The concentrated liquor was preheated to 160 to 180°F to permit satisfactory atomization. Success of the operation depends largely on the performance of the fuel nozzle; detailed design of a nozzle is given. Best results were attained with steam atomizing nozzles. Stable and effective combustion occurred when firing liquor at 52 to 58 per cent solids at rates ranging from 5 to 6.75 lb/min. Gavrilescu (53) stated that the amount of sulfur dioxide in sulfite waste liquor should be more than adequate to destroy the free chlorine produced in making hypochlorite solution from calcium chloride. A combination of the two waste streams should eliminate any free chlorine in the final effluent.

Lewis (94) described a solvent extraction process which more nearly resembles ion exchange. The process, properly called liquid-liquid extraction, was developed for production of uranium concentrates but it appears to offer a wide range of possibilities for recovery of metals from industrial wastes. In a typical uranium recovery by liquid extraction, a water-insoluble organo phosphate is dissolved in kerosene to form a water immiscible organic phase. This phase is then intimately mixed with the uranium-pregnant sulfuric acid solution from leaching the ore. During a brief mixing period, uranium cation leaves the aqueous phase and associates with the organic; simultaneously, an equivalent amount of hydrogen ion migrates from the organic to the aqueous phase. After settling to separate the two phases the organic phase is decanted and uranium-free aqueous phase is run to waste or to by-product recovery. The organic phase is then stripped of its uranium by reversing the extraction

process. By suitable adjustment of the volumes of the two phases it is possible to concentrate the uranium more than 100-fold. The process can be used for recovery of various anions and cations. For example, amine extractants will pick up chromates, vanadates, and uranates but reject ferric iron; the organo phosphates will pick up vanadium in the reduced state, and such positive ions as titanium, copper, zinc, molybdenum, ferric iron, and trivalent chromium. This is such a new technique that data on specific applications are quite meager, but it offers a promising field for exploration.

Additional References

Anon., "Toughest Waste Problem Beaten." *Eng. News-Rec.*, **160**, 22 (1958).

Anon., "Pickle Liquor Disposal Made Practical." *Steel*, **143**, 76 (1958).

Besselievre, E. B., "Auto Wastes Pretreated for Discharge into City Sewers." *Wastes Eng.*, **29**, 690 (1958).

Brink, R. J., "The New Buick Waste Disposal and Oil Reclamation System." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 329 (1957).

Gough, C., "Ion Exchange Operating Problems at Perfect Circle." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 553 (1957).

Kallin, F., "Industrial Waste Treatment." *Proc. 12th. Ind. Waste Conf.*, Purdue Univ., **94**, 364 (1957).

Kilmer, J. J., and Jordan, R. K., "AC Spark Plug Division's Waste Water Treatment Programs." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 1 (1957).

Milligan, F. B., "Bethlehem Steel Improves Acid Pickling Wastes Treatment Plant." *Wastes Eng.*, **29**, 258 (1958).

Noisette, M. G., "Residual Waters from Pickling and Galvanizing Process." *Eau* (France), **44**, 137 (1957); *Pub. Health Eng. Abs.*, **38**, 6, 19 (1958).

Plating and Cyanide Wastes

Trends (49)(109) in waste treatment continue in the direction of waste reduction and water conservation.

Papers by Gruner (62) and Gurnham and Gruner (64) described the technique of incineration of cyanide wastes. Solid cyanide wastes are pulverized with scrap iron in a rotating barrel provided with two hollow trunnion supports through one of which air can be forced when the wastes are finely ground. This air stream carries the cyanide dust through the other trunnion to an incinerator where the cyanide compounds are burned in the flame of mixed waste solvents. Complete destruction of the cyanides is obtained.

A method for destroying cyanide-bearing wastes in aqueous solution as reported by Byrne, Turnley, and Williams (25) consists of saturating the solution with sodium chloride, then electrolytically generating chlorine within the waste solution. It is claimed that virtually complete destruction of cyanide can be achieved at significantly lower operating cost than by direct addition of chlorine gas or hypochlorites because of the low cost of salt and the fact that only one kwhr is needed to destroy 0.08 to 0.1 lb of cyanide. In addition, most plating chemicals can be recovered on the cathode, thereby reducing the sludge problem. The study was carried out with a solution containing cadmium cyanide; graphite anodes and cadmium cathodes were used.

Papers referring specifically to treatment plant operation are referred to at the end of this section, but one such paper deals with the presence of hexavalent chromium in oxidized cyanide effluent and is therefore of general interest. The design of the waste treatment plant of an automobile facility as reported by Delos (40) called for the oxidation of cyanide wastes by chlorine (30 to 50 mg/l residual), a 30 min retention, then to a holding basin where cyanide concentration could be checked before the effluent was sent to the stream. It was found that significant amounts of hexavalent chromium appeared in the holding basin effluent although all chromium wastes had been segregated and directed elsewhere for treatment. It was found that the copper plating solutions contained chromium, not as hexavalent

because the untreated cyanide waste gave negative CrO_3 results, and that chlorination in the presence of copper salts over a period of time caused the elaboration of chromate ion. As a result all cyanide wastes containing chromium compounds after chlorination are directed to the alkaline-oily waste system for reduction of the chromium before release to the stream.

Studies by Ware (155) of the effect of temperature on the biological destruction of cyanide carried out in a laboratory in filters inoculated with *Actinomyces* indicate that the breakdown of cyanide is essentially complete at normal room temperature. The cyanide loading was 80 mg/l (as KCN), and only below 10°C and above 35°C was the biological breakdown of cyanides inefficient. The cyanide was converted to ammonia, nitrate, and nitrite, the proportion of ammonia being higher when the cyanide conversion was lower, *i.e.*, below 10°C or at 35°C and higher.

Continuing earlier studies on the fate of chromium and iron during the treatment of sewage, Stones (144) studied the changes in concentration of copper in sewage. It was found that activated sludge treatment removes about 80 per cent of the copper present in the settled sewage, the remainder passing out with the effluent.

The helpful compilation of local authority by-laws regulating English metal finishing effluents was extended by Meston (107), and Gurnham and Foulke's bibliography (63) of articles dealing with plating wastes appeared in the August issue of *Plating* as usual.

Additional References

Anon., "Trade Effluent Treatment at Vauxhall Motor Plants." *Surveyor*, **117**, 467 (1958).

Arden, T. V., "Ion Exchange in the Treatment of Trade Wastes." *Surveyor*, **117**, 257 (1958).

Besselievre, E. B., "Pontiac Motors Treats Its Wastes." *Wastes Eng.*, **29**, 642 (1958).

Brink, R. J., "The New Buick Waste Disposal and Oil Reclamation System." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 327 (1958).

Douavenza, P., "A Plant for the Treatment of Plating Wastes." *Metalloberfläche* (Germany), **12**, 22 (1958).

Garrett, R., Garland, R., and Sawyer, T., "How Trans-World Airlines Treats Plating Shop Wastes." *Plating*, **45**, 847 (1958).

Gough, C., "Ion Exchange Operating Problems at Perfect Circle." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 553 (1958).

Hartung, K. H., "Reliable Waste Treatment and Neutralization." *Metalloberfläche* (Germany), **12**, 17 (1958).

Keating, R. J., "Recovery or Disposal of Plating Wastes." *Metal Finishing*, **56**, 46 (1958).

Kilmer, J. J., and Jordan, R. K., "AC Spark Plug Division's Waste Water Treatment Program." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 1 (1957).

O'Kane, G. J., "Planning and Operating an Industrial Waste Disposal Plant." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 508 (1958).

Pettet, A. E. J., "Treatment of Plating Wastes and Cyanides." Water Pollution Research Laboratory Reprint 307 (1958).

Pettit, G. A., "Mill Scale Wastes." *Ind. Wastes*, **3**, 133 (1958).

Robbins, B. H., "Practical Methods of Disposing of Cyanide Wastes." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 415 (1958).

Rothstein, S., "Five Years of Ion-Exchange." *Plating*, **45**, 835 (1958).

Whalen, J. M., "Operating Problems of Industrial Wastes Treatment Plants. I. Plating, Heat Treating, and Painting Wastes." THIS JOURNAL, **30**, 11, 1379 (Nov. 1958).

Wiener, R., "Wastes in Metal Industry." Eugen G. Leuze Verlag, Saulgau/WTTBG (Germany) (1958).

Pulp and Paper Wastes

Saunders (134) presents a brief review of the efforts made by the pulp and paper industry to abate stream pollution. Emphasis is placed on the fact that the industry has spent over $100 million during the past ten years to combat pollution and is currently spending over $1 million each year on research alone. A review of the various abatement measures used in the Pacific Northwest is presented by Amberg (3). Research projects in the states of Oregon and Washington are also discussed and since 1947, a total of

$2,835,000 has been spent by the pulp industry on research directly related to solving the disposal problems of the industry. It has been calculated that $8 million have been invested in pollution abatement measures in these two states, which have placed strong emphasis on the elimination of pollution problems. Studies conducted on pulp mill effluents at the University of Washington are discussed by Felicetta and McCarthy (48). These investigators are studying the components of wastewaters from pulp and paper mills, their utilization, and disposal, as well as the chemistry of wood and lignin.

The older methods of sewage treatment, in particular some chemical treatment and sedimentation processes, have not been successful in treating pulp and paper mill wastes. These methods, according to Gehm (55), have required the development of other techniques, such as flotation and direct filtration methods, to extend the scope of clarification to a greater number of wastes. In the field of oxygen demand reduction, biological sewage treatment methods have proved useful in some instances, but not very effective or efficient in others. Gehm (54) also discusses new approaches to the treatment of pulp and paper mill effluents investigated during 1957 by the National Council for Stream Improvement. The three basic problems being studied are: (a) the dewatering and disposal of sludges obtained from clarification processes, (b) color reduction from bleaching wastes, and (c) removal of BOD. The application of centrifugation to the dewatering of sludges is being investigated and an aerobic thermophilic digester for the decomposition of organic residues has been designed and erected. Vacuum filtration of kraft bleach liquors through a bed of hydrated lime has been found extremely effective in removing color and this process is being studied on a larger scale.

Increased efforts are being expended to improve dissolved oxygen conditions below pulp mill outfalls. For example, the Sulphite Pulp Manufacturers Research League (8) is engaged in an experiment designed to increase the dissolved oxygen content of river waters. Hydroelectric turbines are modified to whip in air as the waters pass through, thus helping to meet the BOD of the waters and to sustain marine life downstream from the mills. The feasibility of the system will depend on resultant turbine power loss and damage. The development of a revolutionary mechanical aerator is presented by Zieminski *et al.* (160). Both vertical- and horizontal-type aerators were developed which, in large-scale tank tests, indicated they can effect an oxygen exchange of 1 lb for each 0.2 kwhr applied. This reduces by 50 per cent the power requirements of devices of this kind and should find application for river aeration, fermentation, and waste aeration processes.

Extensive interest has been shown in the development of wood pulp potentials in California and southern Oregon. Arvola (13) reports on a study conducted with the objective of determining the relationship of water quality and pollution control problems to the pulp mill potential in the State of California. The characteristics of various pulp and paper mill effluents are presented by Gaudy (51). Effluent characteristics and some of the problems of the pulp industry in Washington are presented by Neale (117).

Sulfite

Although sulfite pulp represents only about 13 per cent of the total U. S. pulp production, the disposal and recovery problems involved are of vital importance. Pitkin and Crosby (122) give the daily spent sulfite liquor volume in the U. S. as 34 mil gal containing about 2,000 tons of chemicals and 10,000 tons of lignin. The authors discuss four principal washing systems used, including blow pit plus vacuum

rewasher, blow tank plus one or more vacuum rewashers, and blow tanks plus two or more washers in a closed counter current system. A panel discussion on pulp washing and collection of solids was also presented by Weston (157).

The sulfite liquor problem remains a primary target of researchers interested in by-product development. Romano (130) reports on a study undertaken to investigate the feasibility of utilizing a fungus fermentation to convert sugars in spent sulfite liquor to fumaric acid. Based on total amount of sugar available, fumaric acid yields of 40 per cent by weight were obtainable, with 75 per cent sugar removal. Dyck (46) describes the Torula yeast plant of Charmin Paper Mills which has sufficient capacity to process all the company's spent sulfite liquor into 5,000 annual tons of high quality protein product. The process of manufacturing and uses of Torula yeast are outlined. Brown (21) conducted a study to determine the potential market value of Torula yeast and bacterial protein concentrate, if these products were to be produced in the Pacific Northwest. Large scale production would be dependent on their utilization as a high-protein feed supplement. The predicted feeding values average slightly over 4¢/lb for Torula yeast and over 5¢/lb for bacterial concentrate.

The operating procedures at two sulfite alcohol plants in Sweden are described by Carlson *et al.* (27). Studies of the effect of various factors on spent sulfite liquor fermentation are summarized and the system for distilling and purifying is described. A patent has been issued to Baecklund (15) on a process of recovering ethyl alcohol from spent sulfite liquor which comprises: fermenting the liquor; evaporating it in multiple effect evaporator; distilling alcoholic condensate from one or more of the effects in exhausting, purifying, rectifying, and demethanalizing columns; and condensing the distilled vapors in the first effect of the evaporator. The problems of the Scandinavian countries are discussed by Makkonen (98). The present utilization of spent sulfite liquor for the production of alcohol, yeast, and roadbinder is not sufficient to alleviate the pollution problem. The best solution in these countries appears to be combustion of spent sulfite liquor with recovery of 60 to 70 per cent of heat. It is estimated that if the pollution problems were solved, Finland could double its production of paper and board.

Gfeller (56) used various strains of *Lactobacillus* which rapidly degraded and fermented the sugars (both hexoses and pentoses) in spent sulfite liquor to produce lactic acid. Several *Clostridium* strains were found to be best for fermenting spent sulfite liquor into acetone and butanol. Müller (113) found that under optimum fermentation conditions up to 80 per cent of the sugars and 50 to 80 per cent of the acetic acid were consumed in the butanol-acetone fermentation.

Harmon (66) discusses the use of spent sulfite liquor for roadbinder and a patent has been issued to Freeman (50) covering a method of stabilizing and waterproofing road surfaces with a mixture of spent sulfite solids, water, and tarry residues from coal distillation. Many additional by-product developments are reported in the technical and patent literature (24) (58) (60) (70) (74) (123) (149) (150). A novel process of recovering sugars from spent sulfite liquor involving solvent extraction is outlined by Luner *et al.* (96).

Although by-product development may offer a tremendous potential, the market at the present time is inadequate to solve the pollution problems of the major segment of the sulfite industry. At the present time, the various recovery systems offer the most promising solution. The first recovery furnace in the eastern United States

for the recovery of spent sulfite liquor has recently been placed in operation at Brown Company's plant and is described by Van Derveer (151) and in a number of other articles (30) (34) (36). The conversion of the mill to magnesium base pulping cost over $5 million and utilizes the largest recovery furnace in the world. The waste liquor is evaporated and burned in a furnace which will burn 750,000 lb/day of red liquor at 60 per cent solids. Chemicals are recovered from the flue gases. Studies on the magnesium base pulping process by Tomlinson *et al.* (146) led to the Magnefite process, which involves cooking with magnesium bisulfite solution without the normal excess of SO_2 and using a higher combined SO_2 concentration than that used for acid sulfite production. Modification of the existing recovery system as part of the Magnefite process is described and its advantages are shown. A plant which effectively destroys over 97 per cent of the total spent sulfite liquor is described by Hawks (68). The two-part operation comprises collecting the ammonia-base spent sulfite liquor in a closed system and evaporating and burning the residue. Advantages and disadvantages of the system are pointed out.

The atomized suspension technique developed by Gauvin (52) and Lee *et al.* (92) is receiving extensive interest but no large scale trials are being scheduled by the sulfite industry. The process consists of atomizing the liquor in the absence of air or other foreign gases into the top of a tower, the walls of which are maintained at a high temperature, and of passing the suspension of droplets through successive zones of evaporation, drying, and chemical treatment, as it proceeds down the tower. Separation of solids and gases is accomplished by conventional means. A plant utilizing the Zimmermann (161) wet combustion process for oxidizing spent sulfite liquor is being built for the Borregaard Paper Co., Norway, for burning waste liquor. In the process, preheated liquor is fed into a reactor where it is mixed with air under high pressure. Typical conditions in the reactor are 500 to 600°F and 1,000 to 2,200 psi. The gases produced are expanded through a turbine, which supplies power for the air compressors and pumps. Additional work on wet combustion is reported by Cederquist (29). Evaporation and burning of spent sulfite liquor are also discussed by Ulfsparre (148).

Henley (73) investigated the effects of atomic radiation on pulp mill wastes and waste constituents. A 1,400-c Cobalt ^{60} isotope source was used and the samples were exposed to doses from 1 to 10 million r. Results indicated that BOD of spent sulfite liquor was slightly increased by doses up to 10 million r and that reasonable doses of radiation produced no beneficial effects. A patent on concentrating spent sulfite liquor by refrigeration has been issued to Reinert (126) and another concentrating process has been patented by Goddard (59). Spray drying of spent sulfite liquor is discussed by Meinhold and Riis (105).

Kraft

A survey of water usage in the southern kraft industry was conducted by a canvass of 30 large mills in 10 states manufacturing over 80 per cent of the pulp produced in this area (115). Notable in the information collected is the widespread and increasing reuse of process water. Water usage reduction has been accompanied by a substantial decline in sewer losses. This report points out what has, and can be accomplished in water reuse as well as in the reduction of pollutional material reaching the mill sewer.

Color removal from kraft mill bleach liquors remains a problem and is being studied at the National Council for Stream Improvements' Louisiana State University project (116). Experiments conducted, indicated that practically

all the color could be removed from kraft pulping and caustic extract effluents by filtration through a bed of hydrated lime. Bench-scale tests appeared promising and a large-scale pilot plant is being erected at a southern pulp mill. Tanaka *et al.* (145) present a clarifications process using iron or aluminum scrap which reduced the color intensity to a level of about 15 to 33 per cent and the BOD to about 30 per cent of the original value. Scrap iron or aluminum is dissolved under constant aeration in the chlorine-carrying waste liquor of the bleaching process, and the resulting liquor is mixed with the colored alkali extraction waste liquor. The ferric or aluminum hydroxide produced, absorbs and precipitates organic colloids and absorbs coloring matter from the combined waste liquors.

Biological purification studies were reported by Marczek and Zielinski (100). Four types of effluents were passed through aerated vessels containing activated sludge and then through trickling filters. Average BOD reductions of 90 to 95 per cent were obtained. The effluents were non-toxic to fish and were odorless. The full-scale activated sludge plant of the West Virginia Pulp and Paper Co. is described by Pearman and Burns (120). Pulping wastes are settled and mixed with bleach plant wastes, activated sludge, and nutrients. The mixed wastes then flow to combination aeration and settling tanks. The effluent goes directly to the river. The plant has a design capacity of 16 mgd and after one year of operation, the treatment plant has effected a recovery of 15 miles of stream.

Some activity in by-product recovery from kraft liquors was reported. Hearon (69) presents a new process for the production of dimethyl sulfide from alkaline lignin. The lignin in kraft black liquors is reacted with sulfur at elevated temperature and pressure to yield dimethyl sulfide. The engineering details of the process are also presented by Meyer and Coma (108) and a Canadian patent has been issued to Cisney and Wethern (31). Shellow and Pickens (138) present a modification of the standard type of sulfate soap collection system which recovers up to 175 lb of sulfate soap per ton of pine pulp.

Semi-Chemical

Shaffer (137) discusses the three commercial processes which have been developed for the recovery of neutral semi-chemical wastes—the Mead, Institute, and Western Precipitation processes. All three processes use the kraft type furnace. The Mead process operates by separating the sulfur from the sodium by carbonation of the green liquor with waste flue gas. The Institute process involves direct sulfitation of the green liquor. The Western Precipitation process uses the furnace as a carbonator and by increasing green liquor concentration, sodium carbonate is salted out. The first commercial-scale installation of the Western Precipitation method has been built at Consolidated Water Power and Paper Company and this installation will process semi-chemical liquor (5) (18). Whitney *et al.* (158) have been issued a patent on the Institute process. The first commercial installation of the Mead process is discussed by Darmstadt (37). More than 80 per cent of the daily cooking chemical requirements have been supplied by the recovery process during normal operating periods.

The possibility of economic recovery of acetic and formic acids from semi-chemical black liquors is discussed by Othmer (119). One possible method of recovery involves evaporating the spent liquor, treating it with sulfuric acid to liberate formic and acetic acids, and extracting with a suitable solvent. Formic and acetic acids are separated and the solvent is recovered by an azeotropic distillation. Diehl (41)

gives a description of the recently completed expansion program at the Sonoco Products Company which was required to permit the economic operation of the new commercial installation for manufacturing acetic and formic acids from black liquor. A Canadian patent has been issued to Copenhauer *et al.* (33) covering a process for acetic and formic acids recovery from black liquor.

Small-scale recovery experiments have also been conducted using the atomized suspension technique by Lee and Gauvin (91). Jackson and Brown (80) published on the oxidation of spent semi-chemical liquors by the Zimmermann process. It was found that the oxidation equipment was easy to operate, corrosion was non-existent, and 92 per cent of the original oxygen demand was removed. A discussion of the principal problems encountered in the evaporation of neutral semi-chemical spent liquor and possible solutions is presented by Dedert and Brown (39).

Activated sludge treatment studies were conducted by Robbins (128) who found that BOD reductions of 73 to 99 per cent could be obtained at loading rates as high as 325 lb/1,000 cu ft of aerator capacity when treating a liquor having an initial BOD of 9,600 mg/l. Seed sludge concentrations as high as 12,000 mg/l were carried in the system.

Paper Mill

A great number of articles have been published covering the subject of fiber recovery from white water. Klinger (87) discusses the flotation type of equipment covering Sveen Pederson, Adka, Sediflotor, and Aeroflotor designs. Some of the advantages of the flotation saveall include its small size and its low costs of maintenance, installation, and supervision. The principles of paper mill effluent purification by filtration, sedimentation, and flotation are discussed by Klenor (86) and the relative advantages and disadvantages of the Joston system are presented. A general review covering the treatment of paper mill wastes is given by Waldmeyer (154), and Smith and Schirtzinger (140) present a program for controlling paper machine effluent losses.

The Kienzle mechanical filter system developed by Voith in Austria is described by Zettl (159). In this system the filtered layer is formed on a rotary screen by multistage suction. The filtered water, still containing some fibers, is evacuated and used to dilute the next charge to the filter, thus constituting a closed cycle. The recovered fibers are removed and reused. A continuous cleaning mechanism for the screen assures effective filtration even with large amounts of resinous materials.

Waste discharges into the Kalamazoo River have been cut effectively by one mill through the use of a Cyclator installation (11). White water from two paper machines flows into the installation at a rate of 6 mgd. Activated silica and alum are used as coagulants. Sludge is pumped into settling basins. Half of the water recovered from the Cyclator tanks is chlorinated and recycled to the paper machines and the remaining water is pumped to the river.

Schmidt (135) discusses a treatment method for strawboard effluents, based on the flocculation of effluents with ammonia and alum; ammonia must be added first followed by the addition of alum. The procedure followed in plant trials is described, and the costs of the purification process are evaluated.

Miner and Keating (110) describe the recovery operation at the Stony Brook, N. J., boxboard mill which has a production capacity of 175 tons/day. Based on pilot-plant studies a recovery plant was constructed which includes a bar screen built into the white water pit, a surge tank elevated to provide gravity flow through the rest of the

system, a rotary sprinkler to break up foam at the top of the open tank, and a sludge-contact clarifier of the Graver Reactivator type.

A description is given of the effluent purification plant of Edward Towgood and Sons, Great Britain (12), makers of specialty papers from rag and other stock. The rag bailer effluent is metered into the main effluent which is screened, and discharged into settling tanks. The supernatant is discharged to the river and the sludge is reduced to a cake containing 60 to 70 per cent moisture in a rotary vacuum filter. The cake is consigned to industry as raw material.

Additional References

Anon., "Wasting Valuable Fibre? Try This Recovery Unit." *Can. Pulp Paper Ind.*, **11**, 70 (1958.)

Anon., "Pulpers Pace Gains in Pollution Control." *Chem. Week*, **82**, 104 (1958).

Anon., "Air-Sea Team Speeds Waste Disposal Line." *Chem. Week*, **83**, 49 (1958).

Anon., "Re-utilization of Spent Liquor in the ALB-Semicell Process." *Osterr. Papier-Ztg.* (Austria), **63**, 15 (1957).

Anon., "Effluent Disposal in West Germany." *Paper-Maker* (London), **135**, 18 (1958).

Chase, S. E., "Flotation Treatment of Sewage and Industrial Wastes." THIS JOURNAL, **30**, 6, 783 (June 1958).

Han, S. T., "Physical Properties of Neutral Sulphite Spent Liquors." *Tappi*, **40**, 921 (1957).

Kleinschmidt, R. V., White, F. O., and Bowen, E. C., "Economics of Thermal Compression Evaporation." *Tappi*, **41**, 86 (1958).

Pehrson, S. O., and Rennerfelt, J., "Bio-Oxidation of Forest Industry Waste Waters." *Svensk Papperstidn.* (Sweden), **61**, 18B, 768 (1958).

Reed, E., "Dewatering of Groundwood Sludge Obtained from the Clarification of Groundwood Mill Effluent for Final Disposal of Sludge and Water." Natl. Council for Stream Imp., Tech. Bull. No. 100 (Nov. 7, 1957).

Richardson, H. L., "Treatment of Pulp Mill Waste Liquors." Canadian Patent 546,998 (Oct. 1, 1957).

Tannery Wastes

Haseltine (67) discussed the joint treatment of tannery wastes and municipal sewage in Williamsport, Pennsylvania. The plant in Williamsport built to treat these wastes was designed to handle average and maximum flows of 1.1 and 2.1 mgd, respectively. Industrial wastes amount to about 400,000 gpd when the tannery is operating at capacity. The treatment plant incorporates primary treatment and chlorination with vacuum filtration and incineration of the undigested sludge. The operation results show that the apparent average BOD removal in the plant was 54 per cent while the suspended solids removal was only 13.7 per cent. This is in marked contrast to the performance obtained in prior tannery waste treatment facilities where sedimentation removed 24.7 per cent of the BOD and 81 per cent of the suspended solids. The difference in results obtained with the tannery-municipal waste mixture was attributed to chemical reactions occurring between the sewage, tannery waste, and vacuum filter filtrate. It was postulated that coagulation of matter originally present in the dissolved state materially increased the suspended solids load but removal of a small amount of this material effected a much higher BOD reduction than would normally be expected. Operation problems encountered in vacuum filtration, incineration, and pre-aeration were also discussed.

Rosenthal (131)(132) described experiments in which the wastewaters from a tannery in Ayer, Massachusetts, were treated biologically on trickling filters and by activated sludge. The wastewaters discharged from the tannery had a pH of 11.8 and a total alkalinity of 1,100 mg/l as calcium carbonate. Carbonation with flue gas followed by sedimentation was used to lower the pH and reduce the alkalinity of the waste prior to biological treatment. The treated wastewater was mixed with domestic sewage and treated successfully on high-rate laboratory trickling filters. No deposition of calcium on the filter was observed. Ex-

periments in which the activated sludge process was used to treat the waste indicate that reductions in BOD of more than 95 per cent can be achieved with loadings up to 100 lb/day/1,000 cu ft of aeration capacity per day.

The construction and operation of a large-scale experimental plant for the treatment of 200 cu m of domestic sewage, 120 cu m of dairy waste, and 300 cu m of tannery wastewaters are described by Bruhne (22). The plant was designed to operate by the Niers Process in which flocculation is effected by iron hydroxide formed in the wastewaters by aeration and agitation of iron filings in a hopper bottom tank. The plant includes a preliminary sedimentation tank and equalization tank, precipitation tank, sedimentation tank, trickling filter, and sludge ponds. The method of treatment proved satisfactory if the pH was maintained in the alkaline range. Chemical treatment reduced, on the average, the permanganate demand by 79 per cent, the BOD by 93 per cent, and further improvement was effected by biological treatment. The optimum results were obtained when periods of retention of 1 hr in the precipitation tank and 2.5 hr in the sedimentation tank were used. The report includes detailed results of operation from June 1954 to October 1955 and construction costs are given.

A valuable contribution was made by Masselli *et al.* (101) to the problem of tannery waste by giving a description of the processes producing wastes and processes employed for the treatment. In terms of 1,000 lb of wet hides processed, pigskin tanning produced 90 to 100 lb of BOD and calfskin tanning produced 70 to 80 lb of BOD. The bulk of this load is produced by soak, unhair, and de-lime and bate. Protein and other substances extracted from the hide produced 50 to 70 per cent of the total load, the balance being produced by the process chemicals. Sulfide used in unhairing produced 10 to 20 per cent of the BOD. The volumes and composition of the wastes produced are given. The concentrated process wastes are discharged intermittently giving rise to great fluctuations in concentration unless equalized. The ingredients causing trouble are lime, sulfide, chromium, tannin, and resultant sludge. Sedimentation is necessary and produces 5 to 10 per cent by volume of sludge. In secondary treatment the pH value should be lowered to 9.0 by carbonation with flue gas. Trickling filters and activated sludge treatment will reduce the BOD by 85 to 95 per cent and sulfide by 100 per cent. If discharging to municipal sewers, equalization, settling, and reduction of total hardness should be practiced.

Additional References

Feikes, L., and Roth, E., "Report on the Development and Operation of a Tannery Effluent Plant." *Leder* (Germany), **8**, 114 (1957); *Pub. Health Eng. Abs.*, **28**, 6, 20 (1958).

Gillissen, G., "Non-Industrial Infection with Anthrax by Waste Waters from Leather Factories." *Desinfekt. u. Gesundheitswes.* (Germany), **49**, 33 (1957); *Water Poll. Abs.* (Brit.), **31**, 883 (1958).

Luckens, M. M., "Evaluation of Tannery Wastes." *Jour. Amer. Leather Chem. Assn.*, **52**, 260 (1957); *Pub. Health Eng. Abs.*, **28**, 5, 25 (1958).

Nowacki, J., "The Use of Milk of Lime and Carbon Dioxide for Treatment of Waste Waters from Tanneries and Flax Retting Plants." *Gaz. Woda i Tech. San.* (Poland), **27**, 84 (1953); *Water Poll. Abs.* (Brit.), **31**, 2208 (1958).

Power, R. M., "The Treatment of Tannery Wastes with Sanitary Sewage at Ayer." *Sanitalk*, **5**, 19 (1957).

Zdena, N., "Influence of Tannery Effluents on the Vah and Demanovka Rivers in Liptovsky Mikoslas." *Kozarstvi*, **6**, 197 (1956); *Chem. Abs.*, **51**, 9983 (1957).

Textile and Wool Scouring Wastes

Ingols (78) reviewed the sources and components of textile wastes, the difficult factors that arise, and the methods that have been successfully utilized in treating these wastes. Souther and Alspaugh (142) also reviewed the

sources of textile wastes and some of the methods available to reduce pollutional loads from these sources. They also reported some additional results of their research on the biological oxidation of alkaline textile wastes by small pilot-plant trickling filters. From their studies they have concluded that the amount of textile waste that can be treated without pretreatment on a trickling filter is limited by the amount of hydroxide alkalinity rather than by the pH of the waste. They have also found that for every 0.1 mg/l of chromium in the waste there was an approximate loss of 1 per cent in BOD removal efficiency.

Petru (121) has shown that a trickling filter handling reused retting waste can be put in operation within a day after the waste is applied so that it can be used in factories working only seasonally. At the end of the retting season the final treatment is difficult because of the high concentration of dissolved solids and high pH value. Dilution of this waste with river water improves the final treatment.

The use of "dispersed growth aeration" for the treatment of flax retting waste in England has been investigated to determine if the effluent produced is suitable for reuse (57). Of special interest is the effect of the process on removal of iron and volatile fatty acids. The necessary reduction in fatty acids was achieved after 24 hr of aeration in the presence of suitable microorganisms. Tests in which the retting wastes were seeded with various microorganisms indicated that inoculation with *E. coli* followed by aeration for 24 hr caused a 60 to 70 per cent reduction in iron content. The only method, however, so far found suitable to reduce the iron sufficiently (to less than 0.5 mg/l) to permit reuse of the water consists of aeration after inoculation with yeast, followed by coagulation with lime and sedimentation.

In a Russian investigation (136), the possibility of using wool industry wastewaters, containing chromium, for irrigation purposes has been investigated both in laboratory experiments and in the field. It has been determined that concentrations of more than 0.1 mg of trivalent or hexavalent chromium per 100 g of soil inhibit nitrification. Irrigation of soil with wastewaters containing chromium caused a 2- to 10-fold increase in concentration of chromium in the soil down to a depth of one meter. Vegetables grown on soil irrigated with the wastewaters containing chromium had 3 to 10 times more chromium than those grown on soil irrigated with water devoid of chromium.

Additional References

Culver, R. H., "Pilot Plant Treatment of Sewage-Textile Waste Mixtures." *Jour. Boston Soc. Civ. Engrs.*, **45**, 3, 227 (July 1958).

Divet, L., "Treatment of Waste Waters." *Rev. Textile-Tiba*, **55** (N.S.), 25 (1956); *Water Poll. Abs.* (Brit.), **31**, 1639 (1958).

Ghyssaert, L., "Purification of Retting Waters. The Application of the Activated Sludge Process in England." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **37**, 186 (1957); *Water Poll. Abs.* (Brit.), **31**, 2002 (1958).

Greene, G., "Experimental Work on the Treatment of the British Celanese Ltd. Trade Waste." *Jour. and Proc., Inst. Sew. Purif.*, Part 2, p. 116 (1957).

Grune, W. N., "Waste Treatment." *Ind. Wastes*, **3**, 112 (1958).

Nemerow, N. L., "Dispersed Growth Aeration of Cotton Finishing Wastes. II. Effect of High pH and Lowered Air Rate." *Amer. Dyestuff Rep.*, **46**, 575 (1957); *Pub. Health Eng. Abs.*, **28**, 8, 69 (1958).

Nosek, F., and Nosek, J., "The Problem of Dye-Works Waste Waters." *Voda*, **33**, 52 (1953); *Water Poll. Abs.* (Brit.), **31**, 437 (1958).

Nosek, J., and Vondrlik, V., "Experiences in the Treatment of Textile Waste Waters on a Percolating Filter of Slag." *Voda*, **32**, 226 (1953); *Water Poll. Abs.* (Brit.), **31**, 439 (1958).

Nosek, J., and Vondrlik, V., "Slag as Filter Material for Treatment of Textile Waste Waters." *Voda*, **33**, 14 (1953); *Water Poll. Abs.* (Brit.), **31**, 440 (1958).

Rudakov, D. I., "Waste Waters from Plants for the Industrial Production of Flax Fibers." *Textile Ind.* (U.S.S.R.), **15**, 12,

22 (1955); *Water Poll. Abs.* (Brit.), **31**, 2003 (1958).

Sierbacek *et al.*, "Purification of Waste Waters from Production of Dyestuff Intermediates." *Chem. Prumysl* (Czech.), **7**, 127 (1957); *Water Poll. Abs.* (Brit.), **31**, 436 (1958).

Spindler, H., and Usse, J., "Treatment of Waste Lyes from the Cellulose, Textile and Similar Industries." Soc. De Produits Chimiques et Engrais D'Auby. French Patent 1,090,598; *Water Poll. Abs.* (Brit.), **31**, 1638 (1958).

Zellwolle, L. A. G., and Sackel, W., "Treatment of Waste Waters of the Viscose Industry." Austrian Patent 180,535; *Water Poll. Abs.* (Brit.), **31**, 667 (1957).

References

1. Abson, J. W., and Todhunter, K. H., "The Biological Treatment of Carbonization Effluents." *Ind. Chem.* (Brit.), **34**, 303 (1958).
2. Aikins, G. A., "Meat Packing Waste Disposal." *Ind. Wastes*, **3**, 55 (1958).
3. Amberg, H. R., "Pollution Abatement by the Pulp and Paper Industry in the Pacific Northwest." Northwest Pulp and Paper Assn., Tacoma, Wash. (1958).
4. Amer. Petroleum Inst., Div. Refining, "Manual on Disposal of Refinery Wastes. Vol. III. Chemical Wastes." 3rd Ed. (1958).
5. Anon., "Recover Pulping Chemicals This New Way." *Chem. Eng.*, **64**, 10, 166 (1957).
6. Anon., "Waste Problem Can Be Licked." *Eng. News-Rec.*, **160**, 20, 29 (1958).
7. Anon., "Plant to Make Coal Dust from Waste Water Sludge." *Eng. News-Rec.*, **160**, 20, 106 (1958).
8. Anon., "Whipping It Up." *Ind. Eng. Chem.*, **49**, 11, 34A (1957).
9. Anon., "Purification Plants for Disposal of Dairy Waste Waters." *Molkerei-Ztg.* (Germany), **12**, 915 (1958).
10. Anon., "Champlin Well Satisfied with New Refinery Disposal System." *Oil Gas Jour.*, **56**, 51, 32 (Dec. 22, 1958).
11. Anon., "Cyclator Helps Solve Problem of Stream Improvement." *Paper Mill News*, **80**, 16 (1957).
12. Anon., "Edward Towgood and Sons Install New Effluent Purification Plant." *World's Paper Trade Rev.*, **148**, 1280 (1957).
13. Arvola, T. F., "Wood Pulp Potentials in California." *Tappi*, **40**, 11, 158 (1957).
14. Atwood, J. S., and Hodge, W. W., "Regeneration of Waste Pickle Liquor to Produce Ferrous Sulfate Monohydrate." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 378 (1957).
15. Baecklund, G., "Method of Producing Ethyl Alcohol Out of Waste Sulfite Liquor in Combination with Evaporation." Canadian Patent 562,250 (Aug. 26, 1958).
16. Barnes, G. E., and Weinberger, L. W., "Internal Housekeeping Cuts Wastes Treatment at Pickle Packing Plants." *Wastes Eng.*, **29**, 18 (1958).
17. Bogan, R. H., "Biochemical Degradation Products—A New Dimension in Stream Pollution." THIS JOURNAL, **30**, 2, 208 (Feb. 1958).
18. Boyer, R. Q., "Recovery of Sodium Base Spent Sulfite Liquors by Use of the Sulfide Recycle." *Southern Pulp Paper Mfr.*, **20**, 10A, 28 (1957).
19. Brady, S., "Pollution Control in the Petroleum Industry by In-Plant Measures." Amer. Inst. Chem. Engrs., Cincinnati, Ohio (Dec. 6–10, 1958).
20. Brooke, D. L., and Capel, G. L., "An Economical Analysis of Alternate Methods of Cull Tomato Disposal in Dade County, Florida." Agricultural Economics Rept. 59-2, Florida Agr. Exp. Sta. (Sept. 1958).
21. Brown, W. G., "Market Potential for Protein Concentrate Produced from Fermentation of Spent Sulfite Liquor." Natl. Council for Stream Imp., Tech. Bull. No. 110 (Nov. 14, 1958).
22. Bruhne, A., "Report on the Construction and Effect of an Experimental Plant for the Treatment of Tannery Waste Waters in Waldbrol." *Limnol. Schriftenreike*, **4**, 17/18, 97 (1957); *Water Poll. Abs.* (Brit.), **31**, 2209 (1958).
23. Bryner, L. C., and Jameson, A. K., "Microorganisms in Leaching Sulfide Minerals." *Applied Microbiol.*, **6**, 4, 281 (1958).
24. Byrd, G. J., "Well Drilling Fluids and Method of Making the Same." Canadian Patent 560,071 (July 8, 1958).
25. Byrne, J. T., Turnley, W. S., and Williams, A. K., "Destruction of Cyanide Wastes by Electrolytic Chlorination." *Jour. Electrochem. Soc.*, **105**, 607 (1958).
26. Canham, R. A., "Comminuted Solids Inclusion with Spray Irrigated Canning Waste." THIS JOURNAL, **30**, 8, 1028 (Aug. 1958).
27. Carlson, G., Holger, G., and Scholander, A., "Alcohol Manufacture at Mooch Domsjo AB; Some Operating Characteristics and Some Plant Scale Studies." *Svensk Papperstidn.* (Sweden), **61**, 18B, 815 (1958).

28. Caster, A. D., "Who is Responsible for Plants Which Treat Process Waste with Sewage?" *Wastes Eng.*, **29**, 80 (1958).

29. Cederquist, K. N., "Some Remarks on Wet Combustion of Cellulose Waste Liquors." *Svensk Papperstidn.* (Sweden), **61**, 2, 38 (1958).

30. Chilton, C. H., "Magnesia Process Buttons Up Sulfite Pulping." *Chem. Eng.*, **67**, 18, 114 (1958).

31. Cisney, M. E., and Wethern, J. D., "Making Dimethyl Sulfide from Pulp Mill Spent Liquors." Canadian Patent 553,323 (Feb. 18, 1958).

32. Colas, R., "The Treatment of Waste Waters from Seasonal Industries." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **37**, 184 (1957); *Water Poll. Abs.* (Brit.), **31**, 350 (1958).

33. Copenhauer, J. E., Biggs, W. A., Baxley, W. H., and Wise, J. T., "Recovery of Acetic and Formic Acids from Black Liquor." Canadian Patent 551,736 (Jan. 14, 1958).

34. Cronan, C. S., "Magnesia Pulping Breaks Pollution Stalemate." *Chem. Eng.*, **67**, 18, 60 (1958).

35. Daniels, E. K., Lutz, J. R., and Castler, L. A., "Pollution Control at Ferndale, Washington." Amer. Petroleum Inst., Div. Refining, Los Angeles, Calif. (May 14, 1958).

36. Darmstadt, W. J., "Magnesium Base Process at Brown's." *Can. Pulp Paper Ind.*, **11**, 8, 26 (1958).

37. Darmstadt, W. J., "Neutral Sulphite Recovery Process." *Tappi*, **41**, 3, 147 (1958).

38. Davies, C. F., and Cooper, H. G., "Improvements Relating to the Treatment of Gas Works Effluent Liquors." Brit. Patent 727,156; *Pub. Health Eng. Abs.*, **38**, 12, 29 (1958).

39. Dedert, W. G., and Brown, J. N., "Evaporation of NSSC Spent Liquor." *Paper Ind.*, **39**, 11, 914 (1958).

40. Delos, J. S., "Hexavalent Chromium: Its Presence in Treated Cyanide Rinse Waters." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 161 (1957).

41. Diehl, W. F., "New Process is Key to Expansion." *Pulp and Paper*, **32**, 9, 54 (1958).

42. Dougherty, M. H., and McNary, R. R., "Activated Citrus Sludge—Vitamin Content and Animal Feed Potential." THIS JOURNAL, **30**, 9, 1151 (Sept. 1958).

43. Dougherty, M. H., and McNary, R. R., "Elevated Temperature Effect on Citrus Waste Activated Sludge." THIS JOURNAL, **30**, 10, 1263 (Oct. 1958).

44. Drabek, B., "Purification of Gas Works Water in Slag Tips." *Paliva* (Prague), **36**, 60 (1956); *Fuel Abs.* (Brit.), **23**, 5, 55 (1958).

45. Drabek, B., "Phenol Recovery by Adsorption Methods." *Vyzkmny Ustav Vodohospodarsky*, **94**, 111 (1957); *Water Poll. Abs.* (Brit.), **31**, 172 (1958).

46. Dyck, A. W. J., "How Charmin Makes Torula Yeast." *Paper Ind.*, **39**, 1, 2C (1957).

47. Faust, S. D., and Orford, H. E., "Reducing Sludge Volume with Crystal Seeding in Disposal of Sulfuric Acid Waste." *Ind. Eng. Chem.*, **50**, 10, 1537 (1958).

48. Felicetta, V. F., and McCarthy, J. L., "The Pulp Mills Research Programme at the University at Washington." *Tappi*, **40**, 851 (1957).

49. Foulke, D. G., "Trends in Waste Disposal." *Metal Finishing*, **56**, 11, 54 (1958).

50. Freeman, H., "Stabilization of Road Surfaces." Canadian Patent 559,612 (July 1, 1958).

51. Gaudy, A. J., "VIII Wastes from Pulp and Paper Processes." Pub. No. 17, State Water Pollution Control Board, Sacramento, Calif. (1957).

52. Gauvin, W. H., "Application of the Atomized Suspension Technique." *Tappi*, **40**, 11, 866 (1957).

53. Gavrilescu, G., "Neutralization of Waste Liquors from Bisulfite and Hypochlorite Solutions." *Celuloza hirtie* (Roumania), **6**, 168 (1957); *Chem. Abs.*, **52**, 5701 (1958).

54. Gehm, H. W., "New and Basic Research Approaches to Liquid Effluent Treatment." *Paper Trade Jour.*, **142**, 16, 40 (1958).

55. Gehm, H. W., "Modern Approaches to Pulp and Paper Mill Waste Problems." THIS JOURNAL, **29**, 12, 1370 (Dec. 1957).

56. Gfeller, P., "Microbiological Utilization of Spent Sulfite Liquor by Fermentation with Special Consideration of Technically Useful Products." Doctorat Dissertation. Eidgenossische Technische Hochschule, Zurich (Germany) (1954).

57. Ghyssaert, L., and Wauters, L., "Report of Tests on the Purification of Flax Retting Waste Waters by Means of Activated Sludge." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **38**, 242 (1957); *Water Poll. Abs.* (Brit.), **31**, 2207 (1958).

58. Giesen, J., "Process for Hydrolizing Sulfite Waste Liquor." Canadian Patent 547,591 (Oct. 15, 1957).

59. Goddard, H. O., "Process for Producing and Concentrating Residual Waste Sulphite Liquor." U. S. Patent 2,816,831 (Dec. 17, 1957).

60. Goss, W. C., "Process of Treatment and Products from Waste Liquors." Canadian Patent 554,282 (Mar. 11, 1958).

61. Greene, G., "Treatment of Trade Waste from British Celanese Factory." *Surveyor*, **116**, 228 (1957).

62. Gruner, C. T., "Incineration as a Means of the Disposal of Solid Cyanides." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 97 (1957).

63. Gurnham, C. F., and Foulke, D. G., "Bibliography on Metal Finishing Wastes, 1957." *Plating*, **45**, 851 (1958).

64. Gurnham, C. F., and Gruner, C. T., "Solid Cyanide Wastes Incineration." *Ind. Wastes*, **3**, 137 (1958).

65. Hall, D. A., "Treatment of Coke Works Effluent with Ozone." *Gas World, Coking Sect.* (Brit.), **52**, 7 (1958); *Jour. Appl. Chem.* (Brit.), **8**, 6, i–574 (1958); *Water Poll. Abs.* (Brit.), **31**, 385 (1958).

66. Harmon, J. P., "Use of Lignin Sulfonate for Dust Control on Haulage Roads in Arid Regions." U. S. Bur. Mines, Inform. Circ. No. 7806 (1957).

67. Haseltine, T. R., "Tannery Wastes Treatment with Sewage at Williamsport, Pennsylvania." THIS JOURNAL, **30**, 1, 65 (Jan. 1958).

68. Hawks, F. C., "How the Rayonier Shelton Mill Disposes of Sulphite Waste Liquor." *Paper Trade Jour.*, **142**, 13, 22 (1958).

69. Hearon, W. M., "The Lignin Dimethyl Sulfide Process." *Forest Prod. Jour.*, **7**, 12, 432 (1957).

70. Hearon, W. M., Lackey, H. B., and Martin, J. B., "Modified Sulfite Waste Liquor and Process for Its Preparation." U. S. Patent 2,822,358 (Feb. 4, 1958).

71. Hedgepeth, L. L., Gabaccia, A. J., Mauriello, C. G., and Senn, H. W., "Planning a Waste Survey." THIS JOURNAL, **30**, 1, 46 (Jan. 1958).

72. Heller, A. N., Clarke, E. W., and Reiter, W. M., "Some Factors in the Selection of a Phenol Recovery Process." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 103 (1957).

73. Henley, E., "Interaction of Nuclear Radiation with Pulping Waste Products." Natl. Council for Stream Imp., Tech. Bull. No. 109 (Oct. 28, 1958).

74. Hickson, R., "Rubber Reinforced by Lignin Complex." Canadian Patent 550,293 (Dec. 17, 1957).

75. Hood, D. W., Stevenson, B., and Jeffrey, L. M., "Deep Sea Disposal of Industrial Wastes." *Ind. Eng. Chem.*, **50**, 885 (1958).

76. Hull, C. D., "Keeping Ahead of Waste Water Disposal Problems." *Petroleum Eng.*, **30**, 3, C32 (1958).

77. Ingols, R. S., "Treating Food Processing Wastes." *Ind. Wastes*, **3**, 95 (1958).

78. Ingols, R. S., "Textile Waste Problems." THIS JOURNAL, **30**, 10, 1273 (Oct. 1958).

79. Irwin, W. H., "Waste Control in Lagoons." Third Western Petroleum Refiners Assn. Water Disposal and Stream Conf., Wichita, Kans. (Oct. 1–2, 1958).

80. Jackson, D. T., and Brown, R. W., "Oxidation of Spent Semi-chemical Pulping Liquors by the Zimmermann Process." *Pulp and Paper*, **32**, 2, 69 (1958).

81. Jasewicz, L., and Porges, N., "Aeration of Whey Wastes. I. Nitrogen Supplementation and Sludge Oxidation." THIS JOURNAL, **30**, 4, 555 (Apr. 1958).

82. Kannemeyer, A., "Satisfactory Purification of Dairy Wastes by Activated Sludge Method." *Molkerei- u. Kaserei-Ztg.* (Germany), **9**, 187 (1958); *Dairy Sci. Abs.* (Brit.), **20**, 387 (1958).

83. Kaplovsky, A. J., "Problems in Handling Poultry Wastes." *Food Tech.*, **12**, 4, 180 (1958).

84. Kirchgessner, N. J., "Phenol Recovery by Use of Isopropyl Ether." THIS JOURNAL, **30**, 2, 191 (Feb. 1958).

85. Klein, A. H., "Operating Problems of Industrial Wastes Treatment Plants. V. Dairy Wastes." THIS JOURNAL, **30**, 11, 1393 (Nov. 1958).

86. Klenor, P., "Purification of Waste Water in the Paper Industry." *Papír a celulosa* (Czech.), **13**, 6, 132 (1958).

87. Klinger, L. L., "What You Should Know about Flotation Saveall Design and Operation." *Paper Trade Jour.*, **142**, 35, 26 (1958).

88. Kraus, L. S., "Combined Domestic–Industrial Wastes Treatment is Practical." *Wastes Eng.*, **29**, 138 (1958).

89. Labergere, J., "Novelties in the Regeneration of Pickling Baths." *Métallurgie* (Paris), **76**, 127 (1954); *Chem. Zentr.* (Germany), **127**, 12678 (1956); *Water Poll. Abs.* (Brit.), **31**, 386 (1958).

90. Lang, E. W., "How to Treat Pickle Liquors in a Small Plant." *Metal Progr.*, **73**, 5, 93 (1958).

91. Lee, G., and Gauvin, W. H., "Chemical Recovery from Neutral Sulphate Semi-chemical Spent Liquors by the Atomized Suspension Technique." *Tappi*, **41**, 3, 110 (1958).
92. Lee, G., Themelis, N. J., and Gauvin, W. H., "Chemical Recovery from Sodium Base Spent Sulfite Liquors by the Atomized Suspension Technique." *Pulp Paper Mag. Can.*, **59**, 3, 140 (1958).
93. Lefebvre, P. H., and Dickinson, D., "Waste Waters of Cannery Industries." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **88**, 114 (1958); *Pub. Health Eng. Abs.*, **38**, 9, 26 (1958).
94. Lewis, C. J., "Possibilities for Liquid-Liquid Extraction in Industrial Waste Treatment." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 378 (1957).
95. Ludzack, F. J., Middleton, F. M., and Ettinger, M. B., "Observation and Measurement on Refinery Wastes." THIS JOURNAL, **30**, 5, 662 (May 1958).
96. Luner, P., Dubey, G. A., Boggs, L. A., and Wiley, A. J., "Upgrading Spent Sulfite Liquor by Sugar Removal." *Forest Prod. Jour.*, **8**, 2, 82 (1958).
97. Lunsford, J. V., and Dunstan, G. H., "Mesophilic Anaerobic Stabilization of Pea Blancher Wastes." In "Biological Treatment of Sewage and Industrial Wastes. Vol. II, Anaerobic Digestion and Solids-Liquid Separation." p. 107. Edited by J. McCabe and W. W. Eckenfelder, Reinhold Pub. Corp., New York, N. Y. (1958).
98. Makkonen, O. A. P., "Wastes from Paper and Pulp Mills. A Problem of the Northern European Countries with Special Reference to Finland." *Bull. World Health Organization*, **14**, 1079 (1956).
99. Mansson, S. O., "Water Economy in the Food Industry." *Tek. Tidskr.* (Sweden), **87**, 713 (1957); *Water Poll. Abs.* (Brit.), **31**, 244 (1958).
100. Marczek, E., and Zielinski, J., "Biological Purification of Kraft Mill Effluents." *Przeglad Papierniczy* (Poland), **13**, 7, 213 (1957).
101. Masselli, J. *et al.*, "Tannery Wastes—Pollution Sources and Methods of Treatment." New England Interstate Water Pollution Control Comm. (1958).
102. McCord, H. B., and Enquist, M., "How to Cut Sludge-Handling Costs When Treating Oil Well Waste Water." *Oil Gas Jour.*, **56**, 44, 101 (Nov. 3, 1958).
103. McCoy, C. E., "Suppression of House Fly Breeding in Tomato Cannery Waste Lagoons by Means of Polyethylene Cover." *Jour. Econ. Entomol.*, **51**, 411 (1958).
104. Meinhold, T. F., and Arnold, E. R., "Submerged Combustion Whips Boron-Caustic Waste Disposal Problem." *Chem. Processing*, **21**, 7, 73 (1958).
105. Meinhold, T. F., and Riis, A., "Spray Drying Sulfite Waste Liquors." *Chem. Processing*, **20**, 12, 58 (1957).
106. Merman, R. G., and Roth, E. R., "Waste and Water Systems Cut Cost at Atlantic." *Power Eng.*, **62**, 10, 80 (1958).
107. Meston, L., "A Review of Local Authority By-Laws on Finishing Trade Effluents." *Products Finishing*, **11**, 1, 80; 3, 102; 4, 74; 5, 82; 6, 86; 7, 67; 8, 68; 9, 66; 11, 74; and 12, 78 (1958).
108. Meyer, W. G., and Coma, J. G., "Dimethyl Sulfide Production from Kraft Pulp Mill Black Liquor." *Chem. Eng. Progr.*, **54**, 5, 178 (1958).
109. Milne, D., "The Conservation Approach to Industrial Waste Control." *Plating*, **45**, 842 (1958).
110. Miner, G. N., and Keating, R. J., "Recovery and Reuse of Boxboard Mill Effluent." *Can. Pulp Paper Ind.*, **11**, 9, 39 (1958).
111. Mitchell, J., and Sediachek, A. C., "Treat Flue Dust to Recover Iron." *Iron Age*, **182**, 13, 96 (1958).
112. Moore, E. W., "Thermal 'Pollution' of Streams." *Ind. Eng. Chem.*, **50**, 4, 87A (1958).
113. Müller, H. P., "Contributions to the Understanding of Butanolacetone Fermentation in Spent Sulfite Liquor." Zurich Juris-Verlag (1957).
114. Nagy, C. K., "The Construction and Operation of an Incinerator for Chemical Plant Wastes." *Proc. 12th Ind. Waste Conf.*, Purdue Univ., **94**, 177 (1957).
115. Natl. Council for Stream Improvement, "Survey of Water Usage in the Southern Kraft Industry." Natl. Council for Stream Improvement, Tech. Bull. No. 97, New York, N. Y. (Aug. 28, 1957).
116. Natl. Council for Stream Improvement, "Development Studies on the Removal of Color from Caustic Extract Bleaching Effluent by the Surface Reaction Process—Part I." Natl. Council for Stream Improvement, Tech. Bull. No. 107, New York, N. Y. (Sept. 8, 1958).
117. Neale, A. T., "Pulp and Paper Mill Wastes in Washington." *Ind. Wastes*, **3**, 2, 29 (1958).
118. Neumann, E. D., Reno, G. J., and Burroughs, L. C., "Modern Waste-Disposal Facilities at Shell's Anacortes Refinery." Amer. Petroleum Inst., Div. Re-

fining, Los Angeles, Calif. (May 14, 1958).

119. Othmer, D. F., "Chemicals Recovery from Pulping Liquors." *Ind. Eng. Chem.*, **50**, 3, 60A (1958).

120. Pearman, B. V., Jr., and Burns, O. B., Jr., "Activated Sludge Treatment of Kraft and Neutral Sulfite Mill Wastes." THIS JOURNAL, **29**, 10, 1145 (Oct. 1957).

121. Petru, A., "Biological Filter Installation and Final Treatment of Re-Used Retting Wastes." *Jour. and Proc., Inst. Sew. Purif.*, Part 4, p. 321 (1957).

122. Pitkin, W. H., and Crosby, H. L., "Sulphite Washing Practices and Trends." *Tappi*, **40**, 11, 204A (1957).

123. Price, F. A., "The Lignosol Saga; Successful Development of Sulphite Liquor Products." *Pulp and Paper Mag. Can.*, **59**, 3, 88 (1958).

124. Raleigh, W. A., "Acid Drainage Controls Coming." *Coal Age*, **63**, 6, 72 (1958).

125. Rao, S., Skukla, J. P., and Kapur, B. D., "Primary Treatment of Sugar Factory Effluents." *Proc. 25th Annual Convention Sugar Tech. Assn.* (India), Part II, 325 (1957).

126. Reinert, A. E., "Method of Concentrating Sulphite Liquor." Canadian Patent 554,779 (Mar. 18, 1958).

127. Remy, E. D., and Lauria, D. T., "Treats Nylon Waste at 30,000 gphr Rate." *Chem. Processing*, **21**, 10, 34 (1958).

128. Robbins, M. H., "Activated Sludge Treatment of Neutral Sulfate Semichemical Waste." Natl. Council for Stream Improvement, Tech. Bull. No. 105, New York, N. Y. (Mar. 24, 1958).

129. Roberts, J. M., "Combined Treatment of Poultry and Domestic Wastes." THIS JOURNAL, **30**, 9, 1186 (Sept. 1958).

130. Romano, A. H., "Fumaric Acid Fermentation of Spent Sulphite Liquor." *Tappi*, **41**, 11, 687 (1958).

131. Rosenthal, B. L., "Treatment of Tannery Waste-Sewage Mixture on Trickling Filters." *Sanitalk*, **5**, 5, 21 (1957); *Water Poll. Abs.* (Brit.), **31**, 669 (1958).

132. Rosenthal, B. L., "Treatment of Tannery Wastes by Activated Sludge." *Sanitalk*, **6**, 1, 7 (1957); *Water Poll. Abs.* (Brit.), **31**, 1085 (1958).

133. Salvadori, A., and Gignes, R., "New Process for Fractionating Phenolic Oil by Azeotropic Rectification With Water and Ethylene Glycol." *Jour. Usines Gaz.*, **81**, 308 (1957); *Fuel Abs.* (Brit.), **23**, 62 (1958).

134. Saunders, H. H., "Pollution Abatement." *Priorities*, **21** (May 1958).

135. Schmidt, H., "Purification of Effluents from Paper and Board Mills Utilizing Straw." *Zellstoff. u. Papier*, **6**, 6, 182 (1957).

136. Sedova, G. P., "On the Question of Sanitary Assessment of Soil Irrigation with Sewage Containing Chromium." *Gigiena i San.* (U.S.S.R.), **23**, 6, 15 (1958); *Water Poll. Abs.* (Brit.), **31**, 2211 (1958).

137. Shaffer, M. R., "Three Commercial Processes Now Available for NSSC Recovery." *Paper Trade Jour.*, **142**, 5, 36 (1958).

138. Shellow, W. S., and Pickens, A. L., "Soap Collection in the Sulphate Process." *Southern Pulp Paper Mfr.*, **21**, 8, 46 (1958).

139. Shturm, L. D., "Studies on Hydrocarbon Assimilation by Microorganisms." *Mikrobiologiya* (U.S.S.R.), **27**, 6, 740 (Nov.–Dec. 1958).

140. Smith, H. A., and Schirtzinger, M. M., "Prevention of Fiber Losses from the Paper Machine System." *Tappi*, **41**, 11, 163A (1958).

141. Sorensen, H. A., and Douty, C. J., "Furnace Design for Burning Calcium-Base Spent Sulphite Liquor." *Tappi*, **40**, 658 (1957); *Pub. Health Eng. Abs.*, **38**, 1–2, 21 (1958).

142. Souther, R. J., and Alspaugh, T. A., "Current Research on Textile Waste Treatment." THIS JOURNAL, **30**, 8, 992 (Aug. 1958).

143. Steffen, A. J., "Treatment of Packing House Wastes by Anaerobic Digestion." In "Biological Treatment of Sewage and Industrial Wastes. Vol. II, Anaerobic Digestion and Solids-Liquid Separation." p. 126. Edited by J. McCabe and W. W. Eckenfelder, Reinhold Pub. Corp., New York, N. Y. (1958).

144. Stones, T., "The Fate of Copper During Treatment of Sewage." *Jour. and Proc., Inst. Sew. Purif.*, Part I, p. 82 (1958).

145. Tanaka, R., Niwa, T., and Ubokata, E., "Process for Clarifying Sulfate Pulp Waste Water." *Jour. Japan Tech. Assn. Pulp Paper Ind.*, **12**, 1, 28 (1958).

146. Tomlinson, G. H., Tomlinson, G. H., II, Bryce, J. R. G., and Tuck, N. G. M., "The Magnetite Process—A New Pulping Method." *Pulp Paper Mag. Can.*, **59**, 247 (1958).

147. Tully, T. J., "Operating Problems of Industrial Wastes Treatment Plants. III. Waste Acid Neutralization." THIS JOURNAL, **30**, 11, 1379 (Nov. 1958).

148. Ulfsparre, S., "Evaporation and Burning of Sulfite Waste Liquor." *Svensk*

Papperstidn. (Sweden), **61**, 18B, 803 (1958).

149. Van Blaricom, L. E., and Gray, K. R., "Separation of Lignosulfonate Fraction from Waste Pulp Liquor." Canadian Patent 547,334 (Oct. 8, 1957).
150. Van Derveer, P. D., "Brown Co.'s MgO Recovery Plant for Sulphite Waste Liquor." *Paper Trade Jour.*, **142**, 26 (1958).
151. Van Derveer, P. D., "How CZ Gets Profits out of Sulphite and Kraft Mill Liquors." *Paper Trade Jour.*, **142**, 46 (1958).
152. Van Kleeck, L. W., "How Can Cities Control and Treat Industrial Wastes." *Wastes Eng.*, **29**, 304 (1958).
153. Vaughn, R. H., York, G. K., II, Klemmick, M. F., and Davis, L. D., "Pretreatment of Brandy Stillage for Disposal in a Municipal Treatment Plant." *Food Research*, **23**, 3, 297 (1958).
154. Waldmeyer, T., "Treatment of Papermill Wastes." *Paper Making*, **76**, 3, 6 (1957).
155. Ware, W. G., "Effect of Temperature on the Biological Destruction of Cyanide." *Water and Waste Treat. Jour.* (Brit.), **6**, 12, 537 (1958).
156. Wasserman, A. E., Hopkins, W. J., and Porges, N., "Whey Utilization—Growth Conditions for *Saccharomyces fragilis*." THIS JOURNAL, **30**, 7, 913 (July 1958).
157. Weston, H. E., "Pulp Washing—A Panel Discussion." *Paper Ind.*, **39**, 1, 38 (1957).
158. Whitney, R. P., Han, Sho-Tang, and Davis, J. L., "Treatment of Spent Sulfite Liquor." U. S. Patent 2,802,-791 (Aug. 13, 1957).
159. Zettl, M., "Filters for the Recovery of Fibers from Effluents." *Papeterie* (France), **80**, 1, 21 (1958).
160. Zieminski, S. A., Vermillion, F. J., and St. Ledger, B. G., "Final Report on Aeration Development Studies." Natl. Council for Stream Improvement, Tech. Bull. No. 112 (Jan. 30, 1959).
161. Zimmermann, F. J., "New Waste Disposal Process." *Chem. Eng.*, **65**, 17, 117 (1958).

INDUSTRIAL WASTES—RADIOACTIVE

General

A summary of waste processing, treatment, and disposal information was prepared by Arnold (23) and covers waste solution characteristics, economics, predictions of activity and volume buildup in a nuclear power economy, potential health hazards, waste storage, decay and shipment, fission product recovery processes, treatment and disposal of low level and intermediate level wastes, and disposal of high level wastes by various methods. Culler (41) discussed the chemical processes for fission product concentration, removal, or fixation. Details are indicated also on evaporation, precipitation processes, and ion exchange and solvent extraction systems for fission product recovery. Extensive reviews of the problem of radioactive waste disposal were prepared by Lieberman (83), who referred to work on the characteristics of radioactive effluents from the reprocessing of reactor fuels and methods for the treatment and safe ultimate disposal of these effluents; by Newell (96), who indicated the purpose and scope of research and development activities carried out by the Atomic Energy Commission; by Straub (120) (121) (122), who described the work of the AEC and others in the handling and treatment of radioactive waste materials; by Terrill (125), who pointed out that reactor operations and uses of radioisotopes constituted the source of immediate problems in this area; by the AEC (132), who outlined waste disposal standards, the present waste situation, and future programs for waste disposal research and development; and by Jammet (70), who indicated the somatic and genetic effects of radiation (including waste sources) on human beings.

Cason (38) prepared a selected bibliography of books and periodical articles relating to radioactive waste disposal. An annotated bibliography containing 698 references on current and proposed radioactive waste processing and dis-

posal practices, decontamination of surfaces, air cleaning, and other related subjects was compiled by Voress, Davis, and Hubbard (135). A wide selection of unclassified report, journal, and book references to publications on the treatment of gaseous, liquid, and solid radioactive wastes was released by the United Kingdom Atomic Energy Authority (131).

The references have been organized under the subject headings of mining and milling operations; fuel reprocessing; and waste handling, treatment, and disposal.

Additional References

Abbatt, J. D., and Willson, B. D., "Principles of Waste Disposal from Nuclear Power Stations." *Atomic Energy Rev.*, **1**, 106 (1957).

Anon., "Outlook for Waste Disposal." *Nucleonics*, **15**, 11, 155 (1957).

Blythe, H. J., "Safe Disposal of Radioactive Wastes." *Chem. Eng. Mining Rev.*, **49**, 8, 59 (1957); *Chem. Abs.*, **51**, 15291 (1957).

Branca, G., "Treatment and Ultimate Disposal of Radioactive Wastes." *Ingegneria Sanitaria*, **5**, 152 (Sept.–Oct. 1956); *Pub. Health Eng. Abs.*, **38**, 7, 14 (1958).

Christ, W., "Radioactive Impurities in Surface Waters and Their Control." *Wasserwirtsch. Tech.* (Germany), **7**, 379 (1957); *Water Poll. Abs.* (Brit.), **31**, 1649 (Aug. 1958).

Dieterich, B., "Production, Properties, Reuse, and Treatment of Radioactive Waste Waters." *Stadtehygiene*, **9**, 10 (1958); *Water Poll. Abs.* (Brit.), **31**, 2020 (Oct. 1958).

Jaeger, T., "Disposal of Radioactive Wastes. I." *Atomkernenergie*, **3**, 190 (1958); *Chem. Abs.*, **52**, 19525 (1958).

Jaeger, T., "Disposal of Radioactive Wastes. II." *Atomkernenergie*, **3**, 273 (July 1958); *Nuclear Sci. Abs.*, **12**, 19, 13077 (Oct. 15, 1958).

Kuster, J. E., "Waste and Disposal System." U. S. Atomic Energy Comm. Rept. CF-56-10-15 (Oct. 1956).

Manowitz, B., and Rodger, W. A., "Status of Radioactive Waste Processing and Accumulation in Presently Operating AEC Research and Production Sites." U. S. Atomic Energy Comm. Rept. BNL-1091 (Apr. 1951).

Otozai, K., "Treatment of Radioactive Wastes." *Kagaku* (Japan), **12**, 298 (1957); *Chem. Abs.*, **52**, 19523 (1958).

Saddington, K., "Fission-Products Disposal." *Chem. Trade Jour.*, **142**, 260 (1958).

Spicyn, W. J., "Problems of Radioactive Waste in Modern Technique." *Nucleonika* (Poland), **2**, 451 (1957); *Nuclear Sci. Abs.*, **12**, 7, 4784 (Apr. 1958).

Terrill, J. G., "Radioactive Waste Discharges from Nuclear Reactors." THIS JOURNAL, **30**, 3, 270 (Mar. 1958).

Townsend, H. D., "Solving the Radioactive Wastes Problem." *Jour. Florida Eng. Soc.*, **11**, 2, 35 (1957).

U. S. Atomic Energy Commission, "Meeting of the AEC Waste Processing Committee, June 26–28, 1950. Part I." U. S. Atomic Energy Comm. Rept. KAPL-364, Part 1 (Sept. 27, 1950).

Watson, K. S., "Waste Treatment in the Atomic Age." THIS JOURNAL, **29**, 8, 901 (Aug. 1957).

Mining and Milling Operations

Uranium and Thorium

The new Davison Chemical Company feed materials plant at Erwin, Tennessee, which employs the pulse-type solvent extraction process for purification of uranium and plutonium, was described (16). Thorium and uranium concentrates from industrial sources were converted to thorium oxides, metal, or alloys and to uranium oxides, tetrachloride, metal alloys, and other components.

Additional References

Bridger, G. L., Shaw, K. G., and Whatley, M. E., "I. Process for Production of Pure Thorium and Uranium Nitrate from Monazite"; Wilhelm, H. A., Tucker, W. D., Giffen, R. H., and Fisher, R. W., "II. Purification of Thorium Nitrate and the Subsequent Production of Thorium Oxide." U. S. Atomic Energy Comm. Rept., ISC-134 (Feb. 26, 1957).

McNamee, R. J., and Wischow, R. P., "Monex Process: Terminal Report." U. S. Atomic Energy Comm. Rept., ORNL-1873 (Mar. 21, 1957).

Uranium

Flow sheets for processing uranium ores appeared in the literature. These included the Plum process for upgrading uranium ores (19); the Le Bouchet (France) plant process for converting ore concentrate to sodium uranate, processing the uranate into oxide, and reducing the oxide to a metal of 99.999

per cent purity (94); and a patented process for producing uranium metal by reducing UF_4 with magnesia (108).

Low-grade uranium concentrates were enriched by sulfuric acid dissolution followed by precipitation with lime or magnesia (56). In a patented process (129), sulfuric acid was added to the uranium-bearing solution to bring the pH to about 1.4, and aluminum metal was used as a reducing agent to convert hexavalent uranium to the tetravalent state, which precipitated selectively as the pH rose.

The effect of roasting on the application of carbonate leaching to carnotite ores to obtain simultaneously high recoveries of uranium and vanadium was discussed (63). Thunaes *et al.* (128) proposed leaching uranium from high carbonate ores at a temperature of about 200°C and a pressure of about 200 psi with a solution containing alkali carbonate, alkali permanganate, and bicarbonate ion, the bicarbonate ion functioning to prevent premature formation of alkali hydroxide and consequent precipitation of diuranate. After leaching is complete, the uranium is recovered by precipitation with NaOH.

A new resin for the recovery of U from H_2SO_4 leach liquors—Permutit SK for resin-in-column operation and Permutit SKB for resin-in-pulp operation—was described (60). It was said to have a high U absorption rate and a fast, complete U elution rate, with good physical and chemical stability. Preparation of UF_4 by ion exchange and electrolysis from impure natural U in ore leach liquors, ore concentrates, or from reactor-irradiated U partially decontaminated by solvent extraction (Excer Process) was detailed by Higgins *et al.* (67). The applicability of acid leach resin-in-pulp and counter current decontamination solvent extraction to Lakeview, Oregon, ores was reported by Millsap and Shimmin (90) and of alkaline leach-resin-in-pulp to Todilto, Mesa Top, and La Sal ores by Thomas and Shimmin (127). Use of small amounts of saturated aqueous solutions of uranyl nitrate for the back extraction of an ether solution of uranyl nitrate and impurities arising from the HNO_3 leaching of ore was the basis of a patent granted to Ruhoff and Winters (109). A patent was issued to Wibbles and Miller (144) for the separation of molybdenum particularly as silicomolybdic or phosphomolybdic acids by contact with activated charcoal from uranium in ether solutions.

Harrington and Ruehle (64) described the method for preparing UO_2 from hexafluoride through an ammonium diurinate intermediate (referred to as ADU brown oxide) and described the improved property of this material as a fuel.

Tsivoglou *et al.* (130) and Whitman and Porter (143) concerned themselves with the problems associated with the release of waste materials from ore processing plants. Studies made in 1955 and 1956 (130) below a number of mills in the Colorado plateau area showed definite evidence of accumulation of radium and other wasted radioisotopes in river mud and biological forms below most mills. Below one mill, algae samples were found to have 1,500 times the radium content of algae taken from a station above the mill. Similar findings were indicated for insect samples. Uranium milling operations may pollute water supplies with iron and manganese, sulfate, nitrate, magnesium, uranium, chloride, and dissolved solids (143). The specific pollutants depend on the particular flow sheet considered. The severity of the pollution problem depends on the size, quality, and ultimate usage of the receiving waters, while the legal aspects depend on the specific state laws involved.

The economic problems of extracting uranium from various grade minerals were examined by Sartorius (110) along with the chemical treatments necessary for their solution.

Thorium

A patent for the recovery of thorium from impurities found in a slag was granted to Fisher (57). In another process described by Fletcher and Ashworth (58), crude thorium hydroxide was dissolved in excess nitric acid, boiled to break down any phosphate complexes, and extracted with tributyl phosphate containing a non-polar organic solvent. Sodium amalgam reduction of thorium chloride to thorium metal (Metallex Process) was detailed by Dean and Ellis (44).

Additional References

Fleck, H., "Problems of Leaching and Digestion of Uraniferous Slags." U. S. Atomic Energy Comm. Rept. NYO-1136 (1951).

Fleck, H., and Summer, J. E., "Problems of Refining Uraniferous Residues." U. S. Atomic Energy Comm. Rept. NYO-1159 (1953).

Johnson, E. R., Doyle, R. L., Mallotte, W. H., and Rutenkroger, E. O., "The Recovery of Uranium from Ether Extraction Waste Residues." U. S. Atomic Energy Comm. Rept. FMPC-532 (1955).

Kellex Corp., "Bulk Storage of Radium Cake —Preliminary Cost Estimates." U. S. Atomic Energy Comm. Rept. KLX-015 (Del.) (Feb. 26, 1957).

McNamee, R., and Wischow, R. P., "Monex Process: Terminal Report." U. S. Atomic Energy Comm. Rept. ORNL-1873 (Mar. 21, 1957).

Robles, E. G., "A Report on the Recovery of Uranium from Residues Containing Large Amounts of Phosphate." U. S. Atomic Energy Comm. Rept. NYO-5160 (1946).

Saunders, E. R., and Carosella, M. C., "Experimentation on the Extraction of Uranium from Western Ores. 1. Pressure Digestion Tests with Sodium Carbonate and Sodium Bicarbonate. 2. Precipitation Tests." U. S. Atomic Energy Comm. Rept. AECD-3767 (Jan. 23, 1957).

Valle-Riestra, J. F., "Carnotite Solvent Extraction Process: Process Description." U. S. Atomic Energy Comm. Rept. DOW-123 (Mar. 6, 1958).

Whatley, M. E., and Bridger, G. L., "Solvent Extraction of Solutions Containing Rare Earths. Preparation of Thorium Compounds from Monazite by Sulfuric Acid Decomposition and Solvent Extraction." U. S. Atomic Energy Comm. Rept. ISC-115 (1950).

Fuel Reprocessing

In two articles, Anderson reviewed fuel reprocessing by aqueous methods, including Redox and Purex processes, enriched fuels, thorium processing, batch dissolution, solvent extraction, "head-end" processes, and ultimate processes (7); and high (volatility) and low (aqueous and pyrometallurgical) decontamination processes (8). A conceptual design was presented of a multi-purpose chemical processing plant for reprocessing spent reactor fuel elements (133). This plant used a number of parallel dissolution systems with a common aqueous extraction system based on the Purex process. Schematic flow diagrams were included for the over-all plant, the dissolution processes, a radioactive off-gas facility, the extraction system, and for processing procedures for various fuel types. A standard daily chemical processing charge of $13,300 was established. The best solution for low cost processing of fuel elements was a packaged reprocessing plant designed to recover uranium, plutonium, and radioisotopes (17) (87). The extraction of cesium-137 and strontium-90 from other fission products would simplify waste storage and disposal.

Additional References

Armstrong, W. W., Gilbert, E. R., and Maloney, J. O., "Survey and Separation Process. I. General Conclusions and Comparisons." U. S. Atomic Energy Comm. Rept. CN-1017 (1957).

Bailes, R. H., "Progress Reports for January, February, March, 1949." U. S. Atomic Energy Comm. Repts., DOW-11 (Dec. 28, 1955), DOW-12 (Dec. 28, 1955), and DOW-13 (Mar. 14, 1958).

Bailes, R. H., "Progress Reports for July, August, September, 1949." U. S. Atomic Energy Comm. Repts., DOW-17 (Dec. 28, 1955), DOW-18 (Mar. 14, 1958), and DOW-19 (Dec. 28, 1955).

Binford, F. T., "Criteria for Use in the Estimation of the Cost of Shipping Contaminated Reactor Fuels." U. S. Atomic Energy Comm. Rept. CF-54-5-229 (Apr. 2, 1957).

Brooksbank, R. E., Chandler, J. M., and Hylton, C. D., "ORNL Metal Recovery

Plant: Processing of ORNL Graphite Reactor Fuel Elements During the Period July and August 1955." U. S. Atomic Energy Comm. Rept. ORNL-2015 (1955).

Culler, F. L., Jr., Blanco, R. E., Goeller, H. E., and Watson, C. D., "An Analysis of Power Reactor Fuel Reprocessing." U. S. Atomic Energy Comm. Rept. ORNL-2265 (Mar. 27, 1957).

Elson, R. E., and Rubin, B., "Radiation Effects in Aqueous Processing of the Fast Breeder Reactor." U. S. Atomic Energy Comm. Rept. LWS-22679 (1957).

Foster, D. L., "The Caustic Dissolution of Unirradiated Uranium-Aluminum Alloy Fuel in a Trickle-Type Dissolver." U. S. Atomic Energy Comm. Rept. CF-55-11-123 (Apr. 4, 1957).

Furman, N. H., and Mundy, R. J., "Extraction of Uranyl Nitrate from Aqueous Solutions." U. S. Patent 2,816,005 (Dec. 10, 1957).

Kellex Corporation, "The Feasibility of Continuous Chelation." U. S. Atomic Energy Comm. Rept. KLX-44 (Mar. 28, 1957).

McVey, W. H., "PWR Fuel Processing." U. S. Atomic Energy Comm. Rept. IDO-14373 (Mar. 14, 1957).

Moore, F. L., "Liquid-Liquid Extraction of Uranium and Plutonium from Hydrochloric Acid Solution with Tri (iso-octyl) Amine; Separation of Uranium and Plutonium from Thorium and Fission Products." U. S. Atomic Energy Comm. Rept. CF-57-6-61 (June 1957).

Peterson, S., "Chemical Separations Process. Part I. (Chapters 1–8, 10, and 11)." U. S. Atomic Energy Comm. Rept. CF-53-12-150, Part 1 (1957).

Shor, R. S., and Vogler, S., "Process of Dissolving Zirconium Alloys." U. S. Patent 2,820,692 (Jan. 21, 1958).

Ullmann, J. W., and Arnold, E. D., "Decay and Storage of Irradiated Fuel." U. S. Atomic Energy Comm. Rept. CF-56-4-51 (Apr. 1956).

Pyrometallurgical Processes

A study was made of the distribution of Pu and the principal fission products between molten U and Mg. From these findings it was stated that a process for continuous extraction of Pu and fission products from molten U would be quite promising (26).

Fused Salt-Fluoride Volatility Processes

In an attempt to find a feasible method for the removal of rare earths from liquid metal fuels, the reaction between fused Na, K, and Mg chloride eutectic mixture and liquid-Bi solution containing small amounts of rare earth and U was studied (68). The transfer of U to the salt phase was very low. Observations were reported of the behavior of several fission product elements in molten NaF-ZrF_4-UF_4 fuels irradiated in the Aircraft Reactor Experiment (106). Static tests showed that the rate of escape was very low, that ruthenium and niobium deposit on the Inconel walls of the fuel containers, and that Sr, Zr, La, and Ce appear to remain in the fuel. It was also suggested that Zr^{95} replace Cs^{137} as a fission monitor in such fuels.

Wymer (147) presented a tentative flow sheet for fused fluoride salt dissolution of U-Zr fuel material, and Burris and Dillon (34) a revised flow sheet for processing EBR-II fuels by oxidative slagging.

Additional References

Bareis, D. W., Mattern, K. L., Foltz, J. R., and Janeves, D. J., "A Program for a Pyroprocessing Development Experiment, Including Remote Refabrication of Reactor Fuel Assemblies." U. S. Atomic Energy Comm. Rept. NAA-SR-Memo-1299 (1955).

Cathers, G. I., and Bennett, M. R., "A Fused Salt-Fluoride Volatility Process for Recovery and Decontamination of Uranium." U. S. Atomic Energy Comm. Rept. ORNL-1885 (Feb. 28, 1957).

Homogeneous Reactors

Insoluble corrosion (except nickel) and approximately 70 per cent of the fission products were effectively removed by centrifugal separation in a hydraulic cyclone operated at reactor temperature and pressure (33).

Uranium Recovery

A simple device to remove Al jackets from Hanford bonded U slugs was described by Alter *et al.* (3). For the industrial realization of uranium purification by liquid-liquid extraction, a three-stage counter current centrifuge extractor was adopted by De Troy

(49). It was reported that extraction conditions may be varied over a wide range. The production capacity and efficiency of extraction were discussed. The use of specific resins containing a predominance of ethylamine groups attached to side chains, benzylamine, ethanolamine, and diethenolamine groups was suggested by Arden (22) for the recovery of uranium in the presence of cobalticyanide. These resins will release the cobalticyanide following treatment with suitable solution permitting continuous reuse. Smith (119) compared a moving bed continuous ion exchange system to a fixed bed system for use in concentrating and decontaminating a U stream following the solvent extraction cycles in the Thorex process.

Additional References

Bridger, G. L., Shaw, K. G., Whatley, M. B., and Bochinski, J., "Production of Pure Thorium and Uranium Compounds by the Acid Dissolution of Monazite Sand." U. S. Atomic Energy Comm. Rept. ISC-170 (Mar. 27, 1957).

Buffum, R. S., Clark, R. E., Duffey, D. K., Quinn, G. F., and Tepe, J. B., "Ether Extraction as a Portion of Separations Process." U. S. Atomic Energy Comm. Rept. CN-2492 (1957).

Flanary, J. R., "(Purex Process) Second Uranium Cycle (CT-51)." U. S. Atomic Energy Comm. Rept. CF-51-8-85 (Aug. 10, 1951).

Lewis, G. W., Jr., and Rhodes, D. E., "Metal Extraction Process." U. S. Patent 2,812,233 (Nov. 5, 1957).

Kelchner, B. L., "The Decontamination of Uranium from Fission Products by the Use of the Uranyl Oxalate Precipitation Reaction." U. S. Atomic Energy Comm. Rept. LAMS-1245 (1951).

Kellex Corporation, "Waste Metal Recovery Process Engineering Summary Report for July 18, 1949–March 1, 1950." U. S. Atomic Energy Comm. Rept. KLX-1068 (1957).

Smith, J. M., Jr., and Bradley, J. G., "Observations and Evaluation of the Decontamination Procedures Employed at Oak Ridge National Laboratories Redox Pilot Plant Equipment." U. S. Atomic Energy Comm. Rept. HW-14532 (1949).

Vitro Corporation of America, "Decontamination of UO_2SO_4 Solutions (57-C)." U. S. Atomic Energy Comm. Rept. KLX-1617 (1952).

Winters, C. E., "Uranium Purification Process." U. S. Patent 2,813,002 (Nov. 12, 1957).

Thorium Recovery

Thorium is a fertile element that can be converted to fissionable uranium-233 by neutron irradiation. Several processes were proposed for its recovery in a pure form from monazite sands containing uranium and rare earths. Calkins and Bohlmann (35) suggested that sands be digested and dissolved in concentrated NaOH, and then diluted, causing precipitation of the uranium, thorium, and rare earth oxides. Further processing separated the rare earths from the uranium and thorium. The latter elements were separated by extraction into tributyl phosphate and back extracted with a weakly acidic solution to remove thorium. Blundell (30) digested the monazite with strong H_2SO_4 at elevated temperatures, cooled the pasty mass, and diluted it with a large volume of water. Treatment of the filtrate provides the basis for separating thorium from rare earths. Digestion of monazite with sulfuric acid followed by careful pH control to separate the three components, with thorium coming out at the lowest pH, was also the basis of the method suggested by Bridger *et al.* (32). Mixed precipitates were purified further to separate uranium and thorium. Separation of thorium and rare earth elements in nitric acid by Dowex-1 was described by Danon (42).

Additional References

Delaplaine, J. W., and Natale, N. R., "Process Engineering Memorandum on TBP Extraction and Purification of Thorium Evaluation of Extended Runs at BMI." U. S. Atomic Energy Comm. Rept. FMPC-1 (1952).

Gresky, A. T., and Wischow, R. P., "Proposal for '25' or Thorex Waste Disposal: Selective Recovery of Fission Products in Relation to the Long-Range Aspects of

Chemical Waste Economics." U. S. Atomic Energy Comm. Rept. CF-55-11-97 (1955).
Reid, R. C., Jury, S. H., Bresee, J. C., and Suddath, J. C., "New Thorium Process-Vital Metal for Industry and Defense." *Chem. Eng. Progr.*, **54**, 4, 76 (1958).
Wischow, R. P., and Mansfield, R. G., "Laboratory Development of the Thorex Process." U. S. Atomic Energy Comm. Rept. ORNL-1994 (1957).

Plutonium Recovery

Following a brief survey of the formation of plutonium in piles, Regnaut (104) reviewed the advantages and disadvantages of the different processes proposed for extracting it from irradiated uranium bars. The results obtained at different stages of the separation were discussed by Faugeras and Regnaut (55), as well as the performance obtained from the apparatus. The method of separating small amounts of plutonium from large amounts of neutron-irradiated uranium must be sufficiently simple to lend itself to remote control (21), and consists of treating the solution with a fluoride (calcium, strontium, lanthanum, or other fluorides) to absorb the Pu. The absorbed Pu was removed by treatment with a soluble oxalate, carbonate, or bicarbonate. Several patents were granted for the recovery of plutonium. These included the purification and concentration of solvent-extracted Pu by oxalate precipitation (88); treatment with a cerium group trifluoride carrier precipitate containing reduced Pu with an acidic solution containing ceric ion, which dissolved the precipitate and oxidized the Pu to the hexavalent state, and contacting with a soluble alkali metal compound and fluoride, which precipitated the rare earth and contaminant ions present but left the plutonium in solution (51); separation of tetravalent Pu from solutions containing it, uranium, and fission products by contacting with diatomaceous earth, silica gel, Fuller's earth, or alumina which preferentially adsorb the Pu (114); separation by differences in solubility between certain salts (*e.g.*, oxalates) of the trivalent Pu and hexavalent uranium (136); treatment of the niobium oxide-plutonium bearing precipitate with HF for separating as non-volatile plutonium tetrafluoride (141); and formation of organic chelate compounds consisting of tetravalent Pu together with a di(salicylal) alkylenedimine (146).

Additional References

Anon., "Decontamination of Crib Wastes (24-A3)." U. S. Atomic Energy Comm. Rept. KLX-1329: 28 pp. (Jan. 18, 1951).
Hyman, H. H., "The Recovery of Neptunium in the Bismuth Phosphate Process for the Separation of Plutonium." U. S. Atomic Energy Comm. Rept. CN-3685 (1946).
Levenson, M., "Pyro-Met Plutonium Flowsheet." U. S. Atomic Energy Comm. Rept. ANAL-ML-SL-1025 (1956).
Mansfield, R. G., "Distillation of Purex Wastes." U. S. Atomic Energy Comm. Rept. ORNL-1472 (1951).
Matherne, J. L., "ORNL Metal Recovery Plant Processing Clementine Reactor Fuel Elements." U. S. Atomic Energy Comm. Rept. ORNL-1941 (1957).

Waste Handling, Treatment, and Disposal

General

Measures taken to keep radioactivity of effluents from a nuclear plant below the maximum level were described by Walter (138). The problem of the treatment and disposal of radioactive waste waters at Chalk River, Ontario, Atomic Energy of Canada, Ltd., was reported by Ophel (100). The following principles were utilized for such control: (a) segregating and reducing wastes at their source, (b) taking advantage of the natural properties of the materials, and (c) following with an intensive and continuous sampling program. Waste disposal practices at Windscale were described (10). Nicholls and Boadle (97) reviewed several filtration methods for radioactive liquids, and described in detail a filter unit designed at the Atomic Energy Research Establishment (Great Britain) offering completely remote han-

dling of an expendable filter. Several articles (81)(82)(124) described the waste disposal facilities and waste disposal practices at Shippingport. Criteria for the ultimate disposal of radioactive wastes were also presented by La Pointe and Brown (81). At Knolls Atomic Power Laboratory, Schenectady, N. Y., liquid waste was collected by controlled drain systems, monitored for radioactivity content, and stored, if necessary, or released to the Mohawk River (86). The precautions taken in the construction of the experimental reactor at Munich, Germany, to prevent pollution by radioactive materials were described by Wieselberger (145).

Additional References

Claxton, C. R., "Radioactive Waste Disposal System: System Description No. 24." U. S. Atomic Energy Comm. Rept. AECU-3606 (Aug. 1956).

Cohn, M. M., German, L. L., and Perleberg, C. N., "Disposal of Liquid Wastes at the Knolls Atomic Power Laboratory." U. S. Atomic Energy Comm. Rept. KAPL-569 (June 3, 1957).

Hill, A. J., Jr., "The Containment Philosophy at the Savannah River Laboratory." *Chem. Eng. Progr.*, **52**, 80 (1956).

LaPointe, J. R., "Estimation of Radioactivity at Power Reactor: Its Treatment and Control." U. S. Atomic Energy Comm. Rept. WAPD-T-419 (1956).

LaPointe, J. R., and Brown, R. D., "Radioactive Material Control." *Ind. Eng. Chem.*, **50**, 980 (1958).

Plötze, E., "Design and Construction of a Model Plant for the Purification of Radioactive Wastes (Decontamination)." *Atomkern-Energie*, **3**, 186 (1958); *Nuclear Sci. Abs.*, **12**, 9773 (1958).

Poole, E. (Translated by), "The Separation of Solid Particles from Liquids by Means of a Cyclone." *Maschinenbau-technik*, **5**, 455 (1956); *Nuclear Sci. Abs.*, **12**, 7164 (1958).

Saddington, K., "The Extraction of Individual Fission Products from Chemical Process Wastes." United Nations Rept. UNESCO/NS/RIC/16 (1957).

Westinghouse Electric Corporation, "A Discussion of the Radioactive Waste Disposal Facilities at the Shippingport Atomic Power Station." U. S. Atomic Energy Comm. Rept. WAPD-T-387 (1956).

Wirta, R. W., "Flowsheet No. 2—Cesium Isolation and Packaging." U. S. Atomic Energy Comm. Rept. HW-53617 (Nov. 14, 1957).

Witkowski, E. J., "Radioactive Waste Disposal and Decontamination Annual Report for 1957." U. S. Atomic Energy Comm. Rept. CF-57-12-143 (Apr. 18, 1958).

Tank Storage

Tank storage is still the only feasible method for the retention of high level wastes. A description of the various types of wastes produced at Savannah River (18) was presented. Before storage in specially designed tanks, the wastes were neutralized. Operating difficulties with steam surges resulting from differential settling of and concentration of radioactivity were described. Storage was reported to cost $1.50 per gallon of stored waste. The wastes resulting from the operation of the pressurized water Army Package Power Reactor at Fort Belvoir, Va., were stored in a 5,000-gal underground carbon steel tank as reported by Medin (89). This tank was cradle-mounted in an underground leakproof concrete vault and vented to the stack. Two 250-gal laboratory waste tanks lined with Amerplate, one of which can be emptied while the other was used, receive laboratory and sampling wastes. At Hanford, O'Neill and Swift stated that the basic intention of the 241-A Storage Facility design was to control the boiling wastes by providing suitable tanks to contain the liquid and a vapor system was provided with suitable seals to control the vapors (99). The limitations of estimating storage costs for the highly corrosive wastes produced at the Idaho Chemical Processing Plant from the recovery of enriched and uranium fuels were reported (134). Costs for reducing and storing these wastes were compared with underground tank storage.

Additional References

Tait, J. H., and Price, J., "Some Calculations on the Shields Necessary for Different Sizes of Effluent Tanks." Rept. AERE-T/M-49, United Kingdom Atomic Energy

Authority (Apr. 18, 1958); *Nuclear Sci. Abs.*, **12**, 10194 (1958).
Weber, M., "Solution of the Permanent Storage of High-Activity Liquid Wastes." *Jaderna Energie*, **4**, 30 (1958); *Chem. Abs.*, **52**, 11607 (1958).
Wilson, E. E., "Design Considerations of Storage Tanks for Radioactive Wastes." *Chem. Eng. Progr.*, **52**, 19, 153 (1956).

Evaporation

A remotely operated evaporator as reported by Carnavos and Hagen (37) was designed for processing radioactive material. It accomplished a three-fold reduction in waste volume with concentration to 70 per cent salt content. The mist eliminator was capable of reducing entrainment by factors of 10^3 to 10^4.

Additional References

Beall, S. E., "Pilot Model Evaporator for Concentration of Radioactive Chemical Wastes." U. S. Atomic Energy Comm. Rept. ORNL-224 (Mar. 19, 1957).
Carnavos, T. C., "Final Report on E. I. du Pont de Nemours Radioactive Waste Concentration Project." U. S. Atomic Energy Comm. Rept. AECU-3791 (Oct. 15, 1956).

Chemical Precipitation

The use of sludge blanket precipitators and vermiculite and other filter or exchange materials for the removal of radioactive materials from waste solutions was described by Seedhouse (115). Tannic acid was utilized for the removal of alpha-emitting radionuclides (U, Pu, or Po) according to Smales and Airey (117). With a delay period of two weeks following such treatment, alpha activity due to thorium and its daughters would be reduced by more than 96 per cent. Waste solutions obtained in processing uranium, fission products, and ammonium nitrate were treated to destroy ammonium nitrate (31). The residual nitrate solutions were treated with an excess of alkyl acid anhydride (acetic anhydride) to form N_2O and acetic acid.

Cantel and Cohen (36) studied the effect of different decontamination agents on the efficiency of treatment of radioactive effluents. They concluded that versene, often used as a decontaminant, did not impede the efficiency of the chemical treatment used. The removal of ruthenium from radioactive waste residues by ferrous sulfate was studied by DeJonghe and D'Hont (46). Better results were obtained than from flocculation or precipitation. The removal of hexavalent uranium was accomplished with equally good results by the use of tannic acid or sodium phosphate. The effect of versene on the removal of radioactive materials was considered and contrary to the experience of Cantel and Cohen (36), reported above, they (46) found that it interfered considerably, but that its interference could be diminished by means of potassium permanganate.

Barton *et al.* reported that cesium-137 was recovered from acidic wastewater following neutralization to precipitate iron, uranium, and most other fission products; acidification; addition of zinc nitrate and potassium ferrocyanide; digestion for at least one hour; and separation of cesium zinc ferrocyanide by centrifugation (27) (28). The cesium zinc ferrocyanide was converted to cesium chloride by any one of three described processes. Cerium-144, rare earth, and strontium-90 would be recovered by a series of process steps which depend on co-precipitation on ferric hydroxide and on the solubility behavior of the rare earth oxalates, of cerium (IV) iodate, and of strontium carbonate (28). The solubility of $SrSO_4$ as a function of temperature and HNO_3 concentration was studied by Jones (72) to evaluate this property as a means of separating strontium from radioactive wastes. The possibility of extracting slightly soluble cesium picrates from HNO_3 solution by butyl alcohol was also investigated. A chemical process using precipitation and filtration was developed to separate Ba^{140} and other fission products from irradiated enriched uranium-stainless steel fuel pins (113). An-

other procedure was described by Ayers and Legler (24) for the recovery of kilocurie quantities of Ba^{140} from short-cooled MTR full elements and was based on the solubility characteristics of barium and barium salts in selected basic and acidic media.

Setter and Russell (116) described chemical coagulation studies for the removal of radioactive materials found in rain, surface and cistern water, and rain water leakings through soil in Cincinnati. Essentially all suspended beta activity and part of the soluble beta activity were removed. Analyses of samples of raw and treated water from the waterworks at Spartanburg, S. C., showed that radioactivity was found in the water supply; that levels increased after rainfall but were insignificant from a health standpoint; and that the water treatment plant removed from 50 to 75 per cent of the radioactive particles (11).

Additional References

Aponyi, T., Recher, W., Schauer, P. J., Tesdahl, T. C., Tullis, J., and Woeste, J., "Pilot Plant Studies of the Ferrous Sulfide Process for the Decontamination of Purex-Type Reactor Wastes. Final Report." U. S. Atomic Energy Comm. Rept. MLM-835 (Mar. 1, 1957).

Mound Laboratory, "Liquid Waste Disposal Research Report for March 5, 1951 to June 4, 1951." U. S. Atomic Energy Comm. Rept. MLM-579 (Mar. 9, 1957).

Mound Laboratory, "Report for Liquid Waste Disposal Research: November 13, 1950 to March 5, 1951." U. S. Atomic Energy Comm. Rept. MLM-554 (1957).

Ion Exchange

Moeller (91) identified the radionuclides in the recirculating cooling water system of the Low Intensity Test Reactor at ORNL by means of gamma spectral analyses and decay studies as being Na^{24}, Np^{239}, Cu^{64}, I^{131}, I^{132}, I^{133}, I^{135}, $Mo^{99} + Tc^{99m}$, Mn^{56}, Sr^{91}, F^{18}, Pa^{233}, Sb^{122}, $Ba^{140} - La^{140}$, Co^{60}, Fe^{59}, Ce^{143}, Ce^{141}, and Te^{132}. These radionuclides originated in corrosion and neutron activation of structural materials in the reactor, in the activation of impurities in the makeup water, and from uranium contamination on or near the surface of aluminum-clad fuel elements. Ion exchange resins in the line removed Na^{24}, Np^{239}, Cu^{64}, Zn^{65}, Co^{60}, $Mo^{99} + Tc^{99m}$, I^{131}, I^{133}, and Ce^{141}. Methods of calculating expected activity from the organic coolant, impurities, and corrosion products from a typical organic cooled and moderated power reactor were described by Piccot (102).

Higgins and Neill (66) outlined a proposed development program for the treatment and disposal of wastes from merchant ship reactors using ion exchange and filters for coolant system cleanup. The development program was concerned with methods of handling and packaging spent resin, filter cake, and rare gases for safe disposal. A process for removing cations from aqueous solution was described by Gleuckauf and Roberts (59). The aqueous solution containing cations was brought into contact with a solid anion exchange substance, insoluble in water and having, at the exchange positions, anions which formed insoluble compounds with the cations. All metal ions except those of alkali metals might be precipitated. These cations might also be separated from each other, or from those of the alkali metals. The precipitate formed on the anion exchange substance may be removed by washing with a suitable aqueous acid or complexing agent. The anions mentioned include hydroxide, carbonate, sulfide, or chromate.

Mixed bed ion exchange resins were evaluated by Lacy and Lindsten (79) on a laboratory scale by batch type treatment and column type operation, and continued on a much larger pilot-plant scale using military equipment by the same workers (80). The investigation indicated the effectiveness of this method for removing the radioactive material and provided some information on the radiation hazards involved. Perhaps the most extensive

study on the use of ion exchange for removal of radioactivity was that reported by Swope (123). Her work with mixed bed ion exchange resins for removing old mixed fission products from tap water showed that the highest decontamination factors were obtained when the water was adjusted to a pH of 2.5 with nitric acid. Other findings indicated a 3 to 1 ratio of anion to cation resin, flow rate not to exceed 2 gpm per cubic foot of resin, and that the capacity of the resin was based on the amount of total dissolved solids in the feed. Mixed bed ion exchange experiences were reported in the treatment of very low-solids water, gamma irradiation canal waters, reactor coolant waters, and waste treatment.

The treatment of radioactive effluents by sawdust was investigated (46) and showed that adsorption on sawdust was a simple, efficient, inexpensive method for the treatment of very large quantities of radioactive wastes.

Small (118) described an ion exchange technique for recovering Tl^{204} free of Cu and other addition agents from old plating baths.

The use of two polyelectrolyte coagulants (Lytron 886 and Separan 2610) was evaluated with a wide variety of shales (78). Reported results showed comparable removal efficiencies with the two substances studied.

Additional References

Burgus, W. H., and Grimmett, E. S., "Evaluation of Waste Disposal by Electrode-Ionization and Clay Absorption." U. S. Atomic Energy Comm. Rept. IDO-14367 (Mar. 14, 1957).

Grover, J. R., "Disposal of Long Lived Fission Products." *Trans. Inst. Chem. Eng.* (London), **36**, 43 (1958); *Water Poll. Abs.* (Brit.), **31**, 1651 (Aug. 1958).

Kellex Corporation, "Project Summary. Decontamination of Dilute Low Activity Wastes (24-A3)." U. S. Atomic Energy Comm. Rept. KLX-1372 (Mar. 12, 1957).

Kraus, K. A., and Nelson, F., "Radiochemical Separations by Ion Exchange." *Annual Rev. Nuclear Sci.*, **7**, 31 (1957).

Morgan, F., and Sizeland, M. L., "Fission Product Separation by Ion-Exchange." United Kingdom Atomic Energy Authority Rept. AERE-C/R-2277 (1957).

Prevot, I., and Regnaut, P., "Use of Ion Exchange Resins for the Concentration and Purification of Uranium." *Energie nucleaire*, **1**, 207 (1957); *Nuclear Sci. Abs.*, **12**, 6531 (May 1958).

Quinlan, K. P., and Barry, R. J., "Development of an Efficient Eluant for Removal of Molybdenum from Anion Exchange Resins." U. S. Atomic Energy Comm. Rept. WIN-27 (1956).

Simon, G. P., and Singley, W. J., "Crud Absorption by Ion Exchange Resins." U. S. Atomic Energy Comm. Rept. WAPD-SFR-PD-105 (May 1956).

Spedding, F. H., Powell, J. E., Svec, H. F., Evans, J. L., and Harrington, R. E., "The Separation of Isotopes by Ion-Exchange Columns." U. S. Atomic Energy Comm. Rept. ISC-475 (Feb. 25, 1957).

Usatenko, Yu. L., and Gureyeva, L. I., "Separation of Aluminum and Zirconium by the Method of Ion-Exchange." *Zavodskaya Lab.*, **22**, 7, 781 (1956); *Nuclear Sci. Abs.*, **12**, 6537 (May 1958).

Electrodialysis

Laboratory studies were reported (15) on the electro-deionization of solutions of nitric acid and aluminum nitrate to permit subsequent treatment of the residual ions by cationic sorption of beds of ion exchange material. The membranes used consisted of anion exchange resin containing tertiary and quaternary ammonium groups. A decontamination factor in excess of 5×10^3 for cationic fission elements was obtained. The removal of aluminum nitrate by electrodialysis, in the same cell used in the nitric acid experiments, resulted in the formation of granular precipitates of hydrous aluminum oxide in the initial stages of denitrification, followed by the formation of the characteristic sticky, gelatinous aluminum hydroxide precipitate in the latter stages of the denitrification. Factors affecting the nature of the precipitate and degree of precipitation included current density, concentration of aluminum nitrate, temperature, and nature of cathode materials. Durham and Goulden (54) report their experi-

ences with electrodialysis in the recovery of HNO_3 from TBP process waste fission product solutions. A continuous process using three cells was devised. When operating under steady state conditions, the catholyte in the last cell had a pH of about 10, and a precipitate containing 80 to 90 per cent of the original β–γ activity was formed. The supernatant solution contained mainly cesium with some strontium and ruthenium. The recovered nitric acid contained about 3 per cent of the initial β–γ activity. Littlejohn (85) described a process in which the precipitations were carried out electrolytically, an anion-permeable membrane separating electrode compartments of the cell in which the fission product was the catholyte. He indicated that up to 85 per cent of the cesium and strontium remained in solution after precipitation of all other fission products, U, and Fe.

The treatment of radioactive neutralized nitric acid waste solution by electrolysis of sodium nitrate solutions and recycle of the caustic formed to neutralize incoming nitric acid waste was detailed by Alter *et al.* (2). A preliminary cost estimate of $2.75 to $2.95 per initial gallon of waste processed was indicated.

Solvent Extraction

Processes were described by Nigon and Penneman (98) for the quantitative separation of americium and plutonium by chloroform extraction of Pu cupferate from HCl solution, and by Walsh (137) for the extraction of $Am(NO_3)_3$ with tributyl phosphate from aqueous solutions containing $NaNO_3$ and HNO_3.

Additional References

Spence, R., and Streeton, R. J. W., "Counter-Current Liquid-Liquid Extraction in Annulus Columns with Shearing Motion." United Kingdom Atomic Energy Authority Rept. AERE-C/R-933 (Sept. 1952).

White, J. C., "Extraction of the Elements with Trioctylphosphine Oxide from Acidic Solutions." U. S. Atomic Energy Comm. Rept. CF-56-9-18 (Sept. 6, 1956).

Froth Flotation

Employing the principles of froth flotation, Monet (92) separated approximately 99 per cent of the solids present in highly radioactive solutions.

Additional Reference

Murray, G. Y., "Flotation of Uraninite from Other Minerals." U. S. Atomic Energy Comm. Rept. MITG-A30 (Apr. 11, 1956).

Fixation

The proceedings of the meeting on fixation of radioactivity in stable, solid media held at Johns Hopkins University, June 19–21, 1957, were published (93) and covered the following subjects:

1. Waste characteristics governing fixation in soils.
2. Chemical processing of the alumina fluid calciner product into alumina silicates.
3. Fixation of fission product into alumina silicates.
4. Fixation of fission products in stable compounds.
5. Resumé of ceramic section of Oak Ridge National Laboratory.
6. Fixation of fission products in ceramic glazes.
7. Fission product disposal in glass.
8. Leaching studies on fired clays containing radionuclides.
9. Evaluation of experimental clinkers.
10. Fixation of active wastes in solid form using natural soils as media for glass formation.
11. Separation of cesium and strontium from calcined metal oxides as a process in disposal of high level wastes.
12. Fixation of radioisotopes on Hanford type soils.
13. Tests of stability.
14. Calcination of aqueous reactor fuel wastes in a fluidized bed.
15. Experiments on fluidized bed calcination of Idaho Chemical Process-

ing Plant wastes using radioactive feed material.

16. Ball kiln calcination of alloy fuel element wastes.

17. Incorporation of fission products into glass.

18. Ultimate disposal of long-lived fission products.

19. High-temperature gas cleaning problems.

20. Heat evolution and dissipation.

21. Problems associated with waste calcination schemes.

22. Sintering of reactor wastes.

23. Problems associated with the formation of ceramic clinkers.

24. Storage of reactor fuel wastes in salt formations.

Amphlett (4) also reviewed the subject and indicated that the fixation of strongly radioactive residues on appropriate siliceous materials (*e.g.*, earth, clay, or natural silicates) was more flexible than the ion exchange method and allowed the processing of sediments and solid materials as well as solutions. Robinson (105) investigated the feasibility of admixing Portland cement, vermiculite, and radioactive waste solutions and firing at 1,220°C. This matrix was leached to check containment of the radioactive waste. The production of usable cesium radiation sources by the montmorillonite clay process was studied at Brookhaven National Laboratory as a means of ultimate disposal of fission products (112). Of the siliceous materials investigated, White and Lahaie (142) stated that nepheline syenite approached closely the requirements of an ideal glass-forming silicate. This silicate could be mixed directly with wastewaters containing nitric acid and fission products to form a solid gel, which on drying and heating to about 1,225°C, resulted in a glass-like material. The requirements of a site for the permanent storage of fission products contained in glass were discussed by Watson *et al.* (140). The most important considerations were the release of fission products from the glass and the removal of the heat generated by fission product decay. Because the quantity of fission products released on contact with water is significant, storage in dry chambers was suggested. When wastewaters containing aluminum from fuel element cladding, cesium-137, strontium-90, and other fission products were mixed with sodium silicate, an aluminum silicate gel was formed which captured the cesium and strontium by both occlusion and reaction (9) (14). The gel could be blown to a disposal pit for burial at a much lower cost than the present method of storage of liquid wastes in steel tanks. One disadvantage was the deterioration of the gel with age, and, if left to stand, it bled water containing some radioactivity. Heating also changed the nature of the gel.

Calcination

The Fluor Corporation was authorized to proceed with a $300,000 waste calcination system at the National Reactor Testing Station (13). This contract was later extended to $3.3 million to carry the project through to completion by February 1960 (12). Jonke *et al.* (73) reported on a new technique for converting solutions of dissolved salts to dry, granular solids by spray injection into a heated bed of fluidized solids. The technique was applied on a pilot-plant scale to the dehydration and calcination of uranyl nitrate and aluminum nitrate solutions. The experimental equipment was described, and the effect of various operating variables on factors such as particle size growth and completeness of calcination were discussed. Interfering ions such as aluminum and zirconium could be separated by calcination of the wastewaters followed by separation of the leachable fission products (essentially cesium and strontium) from the insoluble aluminum and zirconium oxides according to Abriss *et al.* (1). The unleachable fission products could be considered fixed in the oxides; the un-

leachable ones could be fixed in clay for ultimate disposal or could be separated by ion exchange for use as sources of radiation.

Ground Disposal

The general problems of disposal into the ground were considered by several authors (5) (6) (65) (95). Rodder (107) cited experimental proof that chemical reactions between earth materials and acid $Al(NO_3)_3$ wastes might prevent injection of such wastes into aquifers, unless the wastes or aquifers were pretreated. Conditions were described that make injection not only feasible but reasonably safe and economical. The problems associated with ground disposal in desert basins were reviewed by de Laguna (47). Disposal of power reactor wastes into deep wells, the hydraulics of wells, thermal considerations of disposal aquifers, regional hydrology, potential deep well disposal areas in the U. S., and the cost of such disposal were considered by de Laguna and Blomeke (48).

To evaluate the applicability of ground disposal in Savannah River Plant soils, the effects of cation concentration and acidity on the movement of radioactive strontium, cesium, and plutonium were investigated in the laboratory by Prout (103). Studies on the movement of these same radioisotopes through tuff local to the Los Alamos area were described by Christenson *et al.* (39), and it was shown that cesium was apparently very tightly bound and resisted leaching by any of the common agents, that plutonium was readily retained but that it could be eluted quite easily by discharges of versene, and that strontium was not retained by the tuff nearly so well as cesium and plutonium and that it was more easily released. Disposal of strontium to soil was to be undertaken with extreme caution and only with foreknowledge of the nature of the soil and its capacity for the ions known to be present in the waste. Because Sr^{90} could be leached by other ions, a disposal area receiving this isotope must be closely guarded so that no other wastes will be discharged which might contain concentrations of ions sufficient to dislodge the previously adsorbed nuclide.

A progress report by Orcutt, Kaufman, and Klein (101) examined several theories concerned with the equilibria and kinetics of ion exchange applicable to estimating the rate of underground movement of radiostrontium. The parameters investigated were the exchange capacity, various expressions of equilibria, the influence of calcium, sodium, and hydrogen ions on the rate of strontium movement, the hydraulic rate of liquid application, and the rate coefficients controlling the ion-exchange reactions. The results indicated that a proper application of existing ion exchange theory would greatly reduce the uncertainties of estimating the rate of radiocontaminant travel through natural media and might ultimately provide criteria for the design of subsurface disposal systems.

Blanchard *et al.* at Oak Ridge National Laboratory (29) discussed studies where radioactive waste and ground water solutions were passed through columns of indigenous Conasauga shale to determine the sorbtive behavior of the radionuclides. Cesium-137, the major radioactive constituent of the basic waste solution, was adsorbed very effectively with a shale to solution distribution ratio of 500. A small fraction of Ru^{106}, the only other radionuclide present in relatively large concentration, was adsorbed per unit weight of shale. This adsorption occurred even after the radionuclide had previously passed through 200 ft of shale. The ruthenium and small amounts of Co^{60} and Sb^{125} present were removed by co-precipitation with lead dioxide after the addition of sodium hypochlorite. By combining co-precipitation with adsorption on shale columns, it was possible to ob-

tain decontamination factors of 2×10^3 for gross beta, 3×10^3 for gross gamma, 4×10^4 for cesium, and 2×10^2 for ruthenium. Cowser and Parker (40) pointed out that the ORNL waste pits received through December 1956 a total of 5.6 mil gal of waste containing 58,000 c of Cs^{137}, 15,000 c of Ru^{106}, and lesser amounts of Sr^{89}, Sr^{90}, Co^{60}, Sb^{125}, and the rare earths. Sodium and nitrate ions accounted for the bulk of the chemical constituents. Results from observation wells confirmed the preoperating estimate of direction and path of waste movement and the seepage of anion materials such as Ru^{106} and NO_3^- through the soil. Lacy (77) reported laboratory experiments on the adsorptive capacity of Conasauga shale for the specific wastes discharged to the ORNL waste pits. Ruthenium appeared first in the effluent.

Membrane asphalt appeared to offer the best lining protection for storage basins for long-term retention of neutralized, partially decayed radiochemical wastes and asphaltic plank material was only slightly less desirable (139).

Additional References

Anon., "Salt Away Atomic Wastes?" *Chem. Eng. News*, **36**, 54 (1958).

Auerbach, S. I., "The Soil Ecosystem and Radioactive Waste Disposal to the Ground." *Ecology*, **39**, 3, 522 (July 1958).

McHenry, J. R., "Adsorption Characteristics of Long Soil Columns." U. S. Atomic Energy Comm. Rept. HW-40990 (June 11, 1958).

Rhodes, D. W., and Nelson, J. L., "Disposal of Radioactive Liquid Wastes from the Uranium Recovery Plant." U. S. Atomic Energy Comm. Rept. HW-54721 (June 3, 1957).

Sewers and Sewage Treatment

Kenny (76) reported that radioactive wastewaters discharged to rivers and sewerage systems in Great Britain included those from atomic energy research establishments and premises, universities and research associations, hospitals, and industry. Radioactivity in sewers was discussed. He concluded that there was little danger to sewer workers owing to the regulated amount of radioactive isotopes discharged, the limited time allowed for work in sewers, the use of safety clothing, and the overestimation of the dose and dose-rate by calculation using the formula for an infinite medium.

Kenny further reported (75) (76) that very little adsorption of radioactivity by sewage solids occurred during primary sedimentation. During treatment by activated sludge or by biological filtration, iodine-131, phosphorus-32, cobalt-60, and carbon-14 were partially adsorbed, while sodium-24, potassium-42, bromine-182 (as bromide), sulfur-35 (as sulfate), strontium-89 and -90, and radioactive tritium passed straight through. Sludge was also considered safe for use as a fertilizer, since the isotopes adsorbed by sludge were not adsorbed by plants. Where discharges take place into streams, care should be taken to ensure that fish are safe for human consumption. The effect of radiophosphorus and radioiodine on anaerobic digestion was reported by Grune *et al.* (61) (62). Gas production, which was used as the criterion to evaluate the effects of radioactive materials, was inhibited at high concentrations of radioactivity, but since similar effects were noted in the controls, the effects were due to chemical toxicity of the added materials.

Stream Discharge

Thomas (126) summarized the factors to be considered prior to discharging radioactive wastes into streams. Experiments on the Mohawk River, New York, and Cochichewick Brook, Massachusetts, using radioactive tracers were described, and showed that discharge to streams is not a satisfactory method of disposal. The theory of purification of radioactive effluent by streams was given. Barker (25) cited the factors that influence the movement of radioactivity in ground and surface waters. In the case of ground

water transport, these included: movement of water, dispersal of dissolved and suspended matter in water, and adsorption of substances by natural materials in contact with water. In surface waters the factors were the movement of dissolved and suspended matter, uptake of radioactivity by aquatic biota, and the manner of dispersal into the receiving stream. According to Davis (43), the chemical and physical properties of radioactive materials that influenced dispersion in streams are state, mass, density, radioactive half-life, chemical state, and the temperature of the effluent which bore them. Nonbiotic limnological factors influencing dispersion were stream morphology, flow volume, velocity, temperature, and water chemistry. Stream biota can significantly affect the dispersion of radioactive contamination by accumulating and retaining certain radioisotopes, and by spreading the contamination through migration.

The factors to be considered in assessing the safe amount of radioactivity discharged to a river were indicated by Lister (84) with reference to the effect of biological concentration in aquatic vegetation, in soils, and in fish; the removal of activity by biological organisms; and the use of the river for water supply, recreational, agricultural, and industrial purposes.

The steps necessary to avoid pollution of surface and ground waters in Switzerland were discussed by Jaag (69). De Jonghe (45) reported that permissible levels of discharge to public waters in Belgium were: β emitters, 10^{-6} μc/ml; Ca-Sr, 2×10^{-8} μc/ml; α emitters, 2.4×10^{-9} μc/ml; and radium, 4×10^{-10} μc/ml. He also described the various waste streams produced and the treatment required before release to the environment.

Additional Reference

Profos, P., "Purification of Radioactive Water in Nuclear Power Plants." *Brennstoff-Warme-Kraft*, **10**, 228 (1958); *Chem. Abs.*, **52**, 17997 (1958).

Ocean Disposal

Radioactive waste disposal at sea was extended during the past year with several private firms licensed by the AEC to collect and dispose of atomic waste materials (20). Waste materials were to be disposed of outside normal shipping lanes at sites selected with the U. S. Coast Guard. Materials were to be packaged in containers (usually 55-gal barrels) heavy enough to insure sinking to 1,000 fathoms. It was announced that the waste containers would not be affected by ocean currents at 1,000 fathoms. Also, there would be no interference with fishing. Dunster (52), and Dunster and Farmer (53) provided data on the five-year experimental program (1952–56) at the Windscale Works and reported that the maximum permissible discharge of fission products to the sea was of the order of 15,000 c per month of total beta activity. Samples of fish, seaweed, sea bed, and shore sand were taken at regular intervals during the period and analyzed. Thus, from these it was indicated that due to marine dispersal processes, maximum permissible discharge rates for this works in c per month are Sr^{90}, 3,000; Ru^{106}, 5,000; Pu^{239}, 200; and total β activity, 15,000. At Livermore (111), disposal of liquid wastes took place at sea in shielded containers following various degrees of concentration, and by direct dispersion of wastes in large volumes of sea water.

Additional References

Anon., "California Withdraws Hearing Demand on Disposal." *Nucleonics*, **16**, 27 (1958).

Anon., "Connecticut Town Protests Disposal License." *Nucleonics*, **16**, 27 (1958).

Anon., "Waste Disposal Notes." *Nucleonics*, **16**, 10, 31 (1958).

Vodyanitskii, V. A., "Discussions on the Atomic Industry Waste Disposal into the Black Sea." *Priroda*, **47**, 2, 46 (Feb. 1958); *Nuclear Sci. Abs.*, **12**, 6590 (May 30, 1958).

Incineration

Jordan (74) developed criteria for evaluating incineration as a process for

the disposal of contaminated waste, indicated design features for a large incinerator installation, and evaluated the usefulness of the process for a small installation.

Economics

The economics of pit storage, when the geological location of the pits did not coincide with the location of the processing plant, was considered by Zeitlin and Ullmann (148).

Legislation

Kenny (76) gave recommendations for legislative control of radioactive effluents. The Royal Decree fixing the concentration limit of radioactive substances was given by Devlamink (50). The resources and the activities in progress by various states for controlling the discharge of liquid and solid radioactive wastes were indicated by Jensen *et al.* (71).

References

1. Abriss, A., Reilly, J. J., and Tuthill, E. J., "Separation of Cesium and Strontium from Calcined Metal Oxides as a Process in Disposal of High Level Wastes." U. S. Atomic Energy Comm. Rept. BNL-463 (1957).
2. Alter, H. W., Barney, D. L., Davidson, J. K., Schafer, A. C., Jr., and Witt, F. J., "Electrolytic Recycle Method for the Treatment of Radioactive Nitric Acid Waste." U. S. Atomic Energy Comm. Rept. KAPL-1721 (1957).
3. Alter, H. W., Beck, C. J., and Coplan, B. V., "A Device to Remove Aluminum Jackets Mechanically from Bonded Uranium." U. S. Atomic Energy Comm. Rept. KAPL-1139 (1957).
4. Amphlett, C. B., "The Fixation of Strongly Radioactive Residues in Solid Form." *Energie nucleaire*, **1**, 80 (Apr.–June 1957); *Nuclear Sci. Abs.*, **12**, 6566 (May 31, 1958).
5. Amphlett, C. B., "Ground Disposal of Radioactive Wastes." *Atomics and Nuclear Energy*, **9**, 6, 194 (1958).
6. Amphlett, C. B., "Ground Disposal of Radioactive Wastes." *Atomics and Nuclear Energy*, **9**, 7, 242 (1958).
7. Anderson, E. L., "Fuel Reprocessing Series. I. Fuel Reprocessing by Aqueous Methods." *Nucleonics*, **15**, 10, 72 (1957).
8. Anderson, E. L., Jr., "Fuel Reprocessing Series. II. Low-Decontamination and Volatility." *Nucleonics*, **15**, 12, 44 (1957).
9. Anon., "Clue to Cheap Waste Disposal?" *Nucleonics*, **16**, 2, 27 (1958).
10. Anon., "Disposal of Atomic Waste at Windscale." *Atomics*, **7**, 12, 437 (1956).
11. Anon., "Filtration Plants Reduce Radioactivity in Raw Water." *Water Works Eng.*, **111**, 157 (1958).
12. Anon., "Fluor Gets Contract to Complete Calcination System." *Nucleonics*, **16**, 11, 27 (1958).
13. Anon., "Fluor Gets AEC Nod on Waste System." *Nucleonics*, **16**, 8, 27 (1958).
14. Anon., "GE Gel May Hold Radioactive Waste." *Chem. Eng. News*, **36**, 2, 42 (1958).
15. Anon., "Ion Transfer Membranes Remove Bulk Electrolytes in Radioactive Wastes." *Chem. Eng. Progr.*, **54**, 2, 93 (1958).
16. Anon., "Nuclear Reactor Feed-Materials Plant." *Chem. Eng. Progr.*, **54**, 4, 142 (1958).
17. Anon., "Packaged Nuclear Fuel Reprocessing Plants Proposed." *Chem. Eng. Progr.*, **54**, 1, 122 (1958).
18. Anon., "Physical Properties of Stored Nuclear Wastes at Savannah River." *Chem. Eng. Progr.*, **54**, 2, 91 (1958).
19. Anon., "Plum Uranium Concentration Explained in Flow Sheet." *Uranium*, **4**, 10, 38 (1957).
20. Anon., "Radioactive Waste Disposal at Sea." THIS JOURNAL, **30**, 5, 633 (May 1958).
21. Anon., "Recovery of Plutonium from Solutions Containing It." British Patent 783,601; *Nuclear Eng.*, **3**, 24, 136 (Mar. 1958).
22. Arden, T. V., "Recovery of Uranium by Ion-Exchange." British Patent 783,591/592; *Nuclear Eng.*, **3**, 24, 136 (Mar. 1958).
23. Arnold, E. D., "Compilation and Analysis of Waste Disposal Information." U. S. Atomic Energy Comm. Rept. CF-57-2-20 (Mar. 12, 1957).
24. Ayers, A. L., and Legler, B. M., "Batch Processing for Kilocurie Production of Barium-140." *Chem. Eng. Progr.*, **54**, 2, 83 (1958).
25. Barker, F. B., "Factors Affecting the Transport of Radioactivity by Water." *Jour. Amer. Water Works Assn.*, **50**, 5, 603 (May 1958).
26. Barney, R. A., and Keneshea, F. J., Jr., "Pyrochemical Separations Methods: II. The Distribution of Plutonium and Fission Products Between Uranium and

Magnesium." U. S. Atomic Energy Comm. Rept. NAA-SR-1324 (1955).

27. Barton, G. B., Hepworth, J. L., McClanahan, E. D., Moore, R. L., and Van Tuyl, H., "Chemical Processing Wastes." *Ind. Eng. Chem.*, **50**, 212 (1958).
28. Barton, G. B., Hepworth, J. L., McClanahan, E. C., Moore, R. L., and Van Tuyl, H. H., "Fission Product Recovery from Chemical Processing Plant Waste Solutions." U. S. Atomic Energy Comm. Rept. HW-48776 RD (Feb. 1957).
29. Blanchard, R. L., Kahn, B., and Robeck, G. G., "Laboratory Studies on the Ground Disposal of ORNL Intermediate-Level Liquid Radioactive Wastes." U. S. Atomic Energy Comm. Rept. ORNL-2475 (Apr. 11, 1958).
30. Blundell, R. W., "Recovery of Thorium from Monazite." British Patent 783,628; *Nuclear Eng.*, **3**, 24, 136 (Mar. 1958).
31. Boyer, T. W., MacHutchin, J. G., and Yaffe, L., "Treatment of Ammonium Nitrate Solutions." U. S. Patent 2,838,368 (June 10, 1958); *Nuclear Sci. Abs.*, **12**, 20, 14413 (1958).
32. Bridger, G. L., Whatley, M. E., and Shaw, K. G., "Separation Process for Thorium Salts." U. S. Patent 2,815,262 (Dec. 3, 1957); *Nuclear Sci. Abs.*, **12**, 10, 6989 (1958).
33. Burch, W. D., "Hydroclone Centrifuging Removes Homogeneous Reactor Fission Products." *Chem. Eng. Progr.*, **54**, 2, 79 (1958).
34. Burris, L., Jr., and Dillon, I. G., "Revised EBR-II Flow Sheet for Fuel Cycle with Fuel Purification by Oxidative Slagging." U. S. Atomic Energy Comm. Rept. ANL-LB-SL-1016 (1956).
35. Calkins, G. D., and Bohlmann, E. G., "Processing of Monazite Sand." U. S. Patent 2,815,264 (Dec. 3, 1957); *Nuclear Sci. Abs.*, **12**, 10, 6990 (1958).
36. Cantel, J., and Cohen, P., "Influence of Some Decontaminating Agents on the Purification of Radioactive Residual Water." *Energie nucleaire*, **1**, 138 (July–Sept. 1957); *Nuclear Sci. Abs.*, **12**, 10, 6567 (1958).
37. Carnavos, T. C., and Hagen, J. W., "High-Purity Evaporator for Waste Concentration." *Nucleonics*, **16**, 2, 125 (1958).
38. Cason, M., "Radioactive Waste Disposal." U. S. Atomic Energy Comm. Rept. UCRL-5068 (Apr. 25, 1957).
39. Christenson, C. W., Fowler, E. B., Johnson, G. L., Rex, E. H., and Virgil, F. A., "Soil Adsorption of Radioactive Wastes at Los Alamos." THIS JOURNAL, **30**, 12, 1478 (Dec. 1958).
40. Cowser, K. E., and Parker, F. L., "Soil Disposal of Radioactive Wastes at ORNL: Criteria and Techniques of Site Selection and Monitoring." *Health Physics*, **1**, 152 (1958).
41. Culler, F. L., Jr., "Section 9.0 to Status Report on the Disposal of Radioactive Wastes." U. S. Atomic Energy Comm. Rept. CF-57-3-114 (Rev.) (Suppl. 1) (Sept. 3, 1957).
42. Danon, J., "Separation of Thorium and Rare-Earth Elements in Nitric Acid Media by Anion Exchange." *Jour. Inorganic Nuclear Chem.*, **5**, 237 (1958).
43. Davis, J. J., "Dispersion of Radioactive Materials by Streams." *Jour. Amer. Water Works Assn.*, **50**, 11, 1505 (Nov. 1958).
44. Dean, O. C., and Ellis, G. K., "The Preparation of Thorium Metal by Sodium Amalgam Reduction of Thorium Chloride: The Metallex Process." *Nuclear Sci. and Eng.*, **4**, 4, 509 (Sept. 1958).
45. DeJonghe, P., "Future Problems Posed by the Discharge of Radioactive Wastes in Belgium." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **2**, 40, 134 (1958); *Pub. Health Eng. Abs.*, **38**, 11, 24 (1958).
46. DeJonghe, P., and D'Hont, M., "Some Studies Applicable to the Chemical Treatment of Radioactive Effluents." *Energie nucleaire*, **1**, 27 (Jan.–Mar. 1957); *Nuclear Sci. Abs.*, **12**, 6565 (May 31, 1958).
47. de Laguna, W., "Desert Basins and Waste Disposal." *Health Physics*, **1**, 195 (1958).
48. de Laguna, W., and Blomeke, J. O., "The Disposal of Power Reactor Waste into Deep Wells." U. S. Atomic Energy Comm. Rept. CF-57-6-23 (June 13, 1957).
49. De Troy, A., "The Extraction of Uranium by a Centrifuge Extractor." *Energie nucleaire*, **1**, 191 (Oct.–Dec. 1957); *Nuclear Sci. Abs.*, **12**, 6560 (May 1958).
50. Devlamink, F., "The Problem of Radioactivity and Legislation on the Discharge of Radioactive Waste Substances in Water." Document No. IGRL-T/W-37 (1956); *Nuclear Sci. Abs.*, **12**, 5177 (Apr. 1958).
51. Dreher, J. L., and Thompson, S. G., "Plutonium Separation Method." U. S. Patent 2,819,143 (Jan. 7, 1958); *Nuclear Sci. Abs.*, **12**, 7000 (May 1958).

52. Dunster, H. J., "Disposal of Radioactive Waste to the Sea During 1956." Rept. IGS-R/R.2, United Kingdom Atomic Energy Authority (1958); *Chem. Abs.*, **52**, 12587 (1958).

53. Dunster, H. J., and Farmer, F. R., "A Summary of the Biological Investigations of the Discharges of Aqueous Radioactive Waste to the Sea from Windscale Works, Sellafield, Cumberland." Rept. IGS-R/R-3, United Kingdom Atomic Energy Authority (Jan. 1958); *Nuclear Sci. Abs.*, **12**, 5949 (May 15, 1958).

54. Durham, R. W., and Goulden, P. D., "Electrodialysis of Fission Product Solutions." Rept. CRDC-614, Atomic Energy of Canada (Mar. 1957); *Nuclear Sci. Abs.*, **11**, 6680 (July 15, 1957).

55. Faugeras, P., and Regnaut, P., "Pilot Plant for Plutonium Extraction at Chatillon. Results of Operation." *Energie nucleaire*, **1**, 123 (July–Sept. 1957); *Nuclear Sci. Abs.*, **12**, 6529 (May 1958).

56. Ferreira, P. M., "Chemical Enrichment of Low-Grade Uranium Concentrates." *Energie nucleaire*, **1**, 63 (Apr.–June 1957); *Nuclear Sci. Abs.*, **12**, 6557 (May 1958).

57. Fisher, R. W., "Method of Recovering Thorium." U. S. Patent 2,816,122 (Dec. 10, 1957); *Nuclear Sci. Abs.*, **12**, 6995 (May 1958).

58. Fletcher, J. M., and Ashworth, G. J., "Production of Thorium Compounds." British Patent 783,195; *Nuclear Eng.*, **3**, 24, 136 (Mar. 1958).

59. Gleuckauf, E., and Roberts, P. J., "Process for Removal of Cations from Aqueous Solution." *Nuclear Eng.*, **3**, 23, 90 (Feb. 1958).

60. Greer, A. H., Mindler, A. B., and Termini, J. P., "New Ion Exchange Resin for Uranium Recovery." *Ind. Eng. Chem.*, **50**, 166 (1958).

61. Grune, W. N., Bartholomew, D. D., and Hudson, C. I., Jr., "Effects of Radioactive Materials on Anaerobic Digestion. I. Radiophosphorus." THIS JOURNAL, **30**, 9, 1123 (Sept. 1958).

62. Grune, W. N., Bartholomew, D. D., and Hudson, C. I., Jr., "Effects of Radioactive Materials on Anaerobic Digestion. II. Radioiodine." THIS JOURNAL, **30**, 11, 1399 (Nov. 1958).

63. Halpern, J., and Forward, F. A., "Effect of Roasting on Recovery of Uranium and Vanadium from Carnotite Ores by Carbonate Leaching." *Trans., Met. Soc. AIME*, **212**, 1, 65 (Feb. 1958).

64. Harrington, C. D., and Ruehle, A. E., "Preparation and Properties of Uranium Dioxide Powder." *Chem. Eng. Progr.*, **54**, 3, 65 (1958).

65. Hess, H. H., and Thurston, W. R., "Disposal of Radioactive Waste on Land." *Trans. Amer. Geophysical Union*, **39**, 467 (June 1958).

66. Higgins, I. R., and Neill, W. J., "Proposed Development Program for Treatment of Radioactive Wastes from Merchant Ship Reactors." U. S. Atomic Energy Comm. Rept. CF-58-3-67 (Mar. 19, 1958).

67. Higgins, I. R., Roberts, J. T., and Hancher, C. W., "Preparing Uranium Tetrafluoride by Ion Exchange and Electrolysis." *Ind. Eng. Chem.*, **50**, 285 (1958).

68. Higgins, J. K., "Some Experiments on the [Fused] Salt Processing of Liquid Metal Fuels." Rept. M/M 194, United Kingdom Atomic Energy Authority (1958); *Chem. Abs.*, **52**, 17996 (1958).

69. Jaag, O., "Radioactivity and Protection of Waters." *Gas- u. Wasserfach.* (Germany), **37**, 225 (1957); *Water Poll. Abs.* (Brit.), **31**, 456 (Feb. 1958).

70. Jammet, H., "Risks of Water Pollution by Radioactive Products." *Eau* (France), **43**, 263 (1956); *Water Poll. Abs.* (Brit.), **31**, 2034 (Oct. 1958).

71. Jensen, E. C., Eldridge, E. F., Everts, C. M., Jr., and Clare, H. C., "Radioactive Waste Problems Facing State Governments." THIS JOURNAL, **29**, 6, 687 (June 1958).

72. Jones, S. S., "Fission Product Separations Study." U. S. Atomic Energy Comm. Rept. KLX-10089 (Nov. 1957).

73. Jonke, A. A., Petkus, E. J., Loedling, J. W., and Lawroski, S., "The Use of Fluidized Beds for the Continuous Drying and Calcining of Dissolved Nitrate Solutions." *Nuclear Sci. Eng.*, **2**, 303 (May 1957).

74. Jordan, H. S., "Problems in the Incineration of Radioactive Waste." *Proc. Health Physics Soc.*, 152 (1957); *Nuclear Sci. Abs.*, **12**, 8414 (July 15, 1958).

75. Kenny, A. W., "The Behaviour of Radioisotopes in Sewage Treatment and the Disposal of Radioactive Wastes to Sewers." *Jour. British Nuclear Energy Conf.*, **2**, 341 (Oct. 1957); *Nuclear Sci. Abs.*, **12**, 6568 (May 30, 1958).

76. Kenny, A. W., "Radioactive Discharge to Sewers and Rivers." *Water Poll. Abs.* (Brit.), **31**, 1079 (May 1958).

77. Lacy, W. J., "Radioactive Waste Disposal Report on Seepage Pit Liquid Waste Shale Column Experiment." U.

S. Atomic Energy Comm. Rept. ORNL-2415 (1957).

78. Lacy, W. J., and de Laguna, W., "Decontaminating Radioactive Water." *Ind. Eng. Chem.*, **50**, 1193 (1958).
79. Lacy, W. J., and Lindsten, D. C., "Removal of Radioactive Contaminants From Water by Ion-Exchange Slurry." *Ind. Eng. Chem.*, **49**, 1725 (1957).
80. Lacy, W. J., and Lindsten, D. C., "Water Decontamination: An Ion Exchange Pilot Plant Study." U. S. Atomic Energy Comm. Rept. CF-55-10-153 (Oct. 21, 1955).
81. LaPointe, J. R., and Brown, R. D., "Control of Radioactive Material at the Pressurized Water Reactor." U. S. Atomic Energy Comm. Rept. WAPD-T-436 (1957).
82. LaPointe, J. R., "Radioactive Waste Disposal System." U. S. Atomic Energy Comm. Rept. AECU-3602 (July 1957).
83. Lieberman, J. A., "Treatment and Disposal of Fuel-Reprocessing Waste." *Nucleonics*, **16**, 2, 82 (1958).
84. Lister, B. A. J., "Safe Disposal of Waste From Atomic Energy Establishments." *Surveyor*, **117**, 497 (1958); *Water Poll. Abs.* (Brit.), **31**, 2019 (Oct. 1958).
85. Littlejohn, A. C., "The Separation of Fission Products by Electrolytic Precipitations." Rept. AERE-C/R-1537, United Kingdom Atomic Energy Authority (Dec. 19, 1956); *Nuclear Sci. Abs.*, **11**, 6679 (July 15, 1957).
86. Manieri, D. A., and Truran, W. H., "Radioactive Waste Disposal at Knolls Atomic Power Laboratory." U. S. Atomic Energy Comm. Rept. TID-8017 (Mar. 1958).
87. Manly, C. G., "More on the Reprocessing Package." *Chem. Eng. Progr.*, **54**, 2, 48 (1958).
88. Maraman, W. J., Beaumont, A. J., Nance, R. L., Roybal, J. C., and Windchester, R. S., "Purification and Concentration of Solvent Extracted Plutonium by Oxalate Precipitation." U. S. Atomic Energy Comm. Rept. LA-1991 (1957).
89. Medin, A. L., "Army Package Power Reactor Water Treatment and Waste Disposal." *Ind. Eng. Chem.*, **50**, 989 (1958).
90. Millsap, W. A., and Shimmin, R. L., "Acid Leach Resin-In-Pulp and CCD Solvent Extraction Pilot Plant Testing of Lakeview Ore." U. S. Atomic Energy Comm. Rept. WIN-78 (1957); *Nuclear Sci. Abs.*, **12**, 6523 (May 1958).
91. Moeller, D. W., "Radionuclides in Reactor Cooling Water—Identification, Source, and Control." U. S. Atomic Energy Comm. Rept. ORNL-2311 (June 12, 1957).
92. Monet, G. P., "Method of Separating Froths from Liquids." U. S. Patent 2,820,759 (Jan. 21, 1958); *Nuclear Sci. Abs.*, **12**, 7005 (May 1958).
93. Morgan, J. M., Jr., "Report of Working Meeting on Fixation of Radioactivity in Stable, Solid Media at the Johns Hopkins University." U. S. Atomic Energy Comm. Rept. TID-7550 (June 19–21, 1957).
94. Moyal, M., "Uranium Ore Reduction. The French Process." *Nuclear Power*, **3**, 125 (Mar. 1958); *Nuclear Sci. Abs.*, **12**, 6561 (May 1958).
95. National Research Council, "The Disposal of Radioactive Waste on Land." U. S. Atomic Energy Comm. Rept. NP-6503 (Sept. 1957).
96. Newell, J. F., "Handling and Disposal of Radioactive Wastes." *Amer. Ind. Hyg. Assn. Quart.*, **19**, 31 (Feb. 1958).
97. Nicholls, C. M., and Boadle, C. D., "Throw-Away Filter Unit for Radioactive Liquids." *Nucleonics*, **15**, 11, 142 (1957).
98. Nigon, J. P., and Penneman, R. A., "Quantitative Separation of Americium and Plutonium Using Cupferron." U. S. Atomic Energy Comm. Rept. LA-1079 (1957).
99. O'Neill, G. L., and Swift, W. H., "Purex Waste Storage. Part I. 241-A Waste Storage Facilities." U. S. Atomic Energy Comm. Rept. HW-41791 (Mar. 7, 1956).
100. Ophel, I. L., "The Disposal of Radioactive Wastes." Rept. AECL No. 450 (1950) Atomic Energy of Canada Ltd.; *Water Poll. Abs.* (Brit.), **31**, 2022 (Oct. 1958).
101. Orcutt, R. G., Kaufman, W. J., and Klein, G., "The Movement of Radio-Strontium Through Natural Porous Media." U. S. Atomic Energy Comm. Rept. AECU-3608 (Nov. 1956).
102. Piccot, A. R., "Prediction of Radioactive Disposal Problems in a Typical Organic Cooled and Moderated Power Reactor." *Health Physics*, **1**, 2, 232 (Sept. 1958).
103. Prout, W. E., "Adsorption of Radioactive Wastes by Savannah River Plant Soil." *Soil Sci.*, **86**, 13 (July 1958).
104. Regnaut, P., "Extraction of Plutonium." *Energie nucleaire*, **1**, 196 (Oct.–Dec. 1957); *Nuclear Sci. Abs.*, **12**, 6530 (May 1958).
105. Robinson, G. C., "Summary of Summer Work on the Incorporation of Radioactive Isotopes in Ceramic Masses."

U. S. Atomic Energy Comm. Rept. CF-58-4-74 (Apr. 16, 1958).

106. Robinson, M. T., Brooksbank, W. A., Jr., Reynolds, S. A., Wright, H. W., and Handley, T. H., "The Behavior of Fission Products in Molten Fluoride Reactor Fuels." *Nuclear Sci. Eng.*, **4**, 3, 288 (Sept. 1958).
107. Rodder, E., "Atomic Waste Disposal by Injection into Aquifers." *Proc. Nuclear Eng. Sci. Congr.*, Part 1, 359 (1957); *Chem. Abs.*, **52**, 13453 (1958).
108. Ruehle, A. E., and Stevenson, J. W., "Production of Uranium." U. S. Patent 2,813,004 (Nov. 12, 1957).
109. Ruhoff, J. R., and Winters, C. E., "Uranium Purification Process." U. S. Patent 2,813,001 (Nov. 12, 1957).
110. Sartorius, R., "Chemical Treatment of Low-Grade Uranium Minerals." *Energie nucleaire*, **1**, 3 (Jan.–Mar. 1957); *Nuclear Sci. Abs.*, **12**, 6555 (May 1958).
111. Schewennesen, J. L., Michels, L. R., and Feldman, M. L., "Process Design for the Livermore Waste Disposal Plant." U. S. Atomic Energy Comm. Rept. LWS-24632 (Apr. 1, 1957).
112. Schoolmeester, J. E., and Martin, J. J., "Preparation of Radiation Sources from Fission Products by the Clay Process." U. S. Atomic Energy Comm. Rept. AECU-3618 (Aug. 1957).
113. Schulte, J. W., "Process Development Studies for Recovering Barium-140 from Irradiated Enriched Uranium Rods." U. S. Atomic Energy Comm. Rept. LA-2037 (1956).
114. Seaborg, G. T., and Willard, J. E., "Separation of Plutonium from Uranium and Fission Products by Adsorption." U. S. Patent 2,819,144 (Jan. 7, 1958).
115. Seedhouse, K. G., "Effluent Treatment. Precipitation Ion-Exchange Methods." *Nuclear Eng.*, **2**, 413 (1957).
116. Setter, L. R., and Russell, H. H., "Chemical Coagulation Studies on Removal of Radioactivity in Waters." *Jour. Amer. Water Works Assn.*, **50**, 5, 590 (May 1958).
117. Smales, A. A., and Airey, L., "Removal of α-Activity from Effluent—Some Experiments on the Use of Tannic Acid and Lime." Rept. C/R-289, United Kingdom Atomic Energy Authority (1957); *Chem. Abs.*, **52**, 112 (1958).
118. Small, H., "The Recovery of Thallium-204 from Old Plating Baths." Rept. AERE-I/M-35, United Kingdom Atomic Energy Authority (Sept. 29, 1954); *Nuclear Sci. Abs.*, **11**, 6654 (July 15, 1957).
119. Smith, D. J., "A Continuous Ion-Exchange System for Uranium Concentration and Decontamination in the Thorex Process." U. S. Atomic Energy Comm. Rept. KAPL-M-DJS-1 (Mar. 15, 1957).
120. Straub, C. P., "Atomic Energy Program for Waste Disposal. Part I." *Ind. Wastes*, **3**, 42 (1958).
121. Straub, C. P., "Atomic Energy Program for Waste Disposal. Part II." *Ind. Wastes*, **3**, 60 (1958).
122. Straub, C. P., "Atomic Energy Program for Waste Disposal. Part III." *Ind. Wastes*, **3**, 91 (1958).
123. Swope, H. G., "Mixed Bed Ion-Exchange for the Removal of Radioactivity." *Jour. Amer. Water Works Assn.*, **49**, 8, 1085 (Aug. 1957).
124. Terrill, J. G., Jr., "Sanitary Engineering and Reactor Waste Disposal." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **83**, SA5, 1407 (1957).
125. Terrill, J. G., Jr., "Some Public Health Aspects of Radioactive Wastes." *Bull. Atomic Scientists*, **14**, 1, 44 (1958).
126. Thomas, H. A., "Disposal of Slightly Radioactive Liquids in Streams." *Bull. Centre Belge Etude et Document. Eaux* (Belgium), **62**, 80; and **65**, 204 (1956); *Water Poll. Abs.* (Brit.), **31**, 431 (Feb. 1958).
127. Thomas, P. N., and Shimmin, R. L., "The Alkaline Leach Resin-In-Pulp Process as Applied to Tobilto, Mesa Top and La Sal Ores." U. S. Atomic Energy Comm. Rept. WIN-77 (Sept. 10, 1957).
128. Thunaes, A., Brown, E. A., and Rabbitts, A. T., "Alkaline Carbonate Leaching Process for Uranium Extraction." U. S. Patent 2,813,003 (Nov. 12, 1957).
129. Thunaes, A., Brown, E. A., Smith, H. W., and Simard, R., "Uranium Precipitation Process." U. S. Patent 2,815,261 (Dec. 3, 1957).
130. Tsivoglou, E. C., Bartsch, A. F., Rushing, D. E., and Holaday, D. A., "Effects of Uranium Ore Refinery Wastes on Receiving Waters." THIS JOURNAL, **30**, 8, 1012 (Aug. 1958).
131. United Kingdom Atomic Energy Authority, "Treatment and Disposal of Gaseous, Liquid and Solid Radioactive Wastes." Rept. IGRL-IB/R-28 (Nov. 1957).
132. U. S. Atomic Energy Comm., "Status Report on Handling and Disposal of Radioactive Wastes in the AEC Program." U. S. Atomic Energy Comm. Rept. WASH-742 (Aug. 1957).
133. U. S. Atomic Energy Comm., "Summary Report: AEC Reference Fuel-Process-

ing Plant." U. S. Atomic Energy Comm. Rept. WASH-743 (Oct. 1957).

134. Vitro Corp. of America, "Economic Evaluation of Potential Methods for Concentrating Reactor Wastes for Storage-Study of Idaho Chemical Processing Plant Wastes." U. S. Atomic Energy Comm. Rept. KLX-1723 (1957).
135. Voress, H. E., Davis, T. F., and Hubbard, T. N., Jr., "Radioactive Waste Processing and Disposal: A Bibliography of Selected Report Literature." U. S. Atomic Energy Comm. Rept. TID-3311 (June 1958).
136. Wahl, A. C., "Process for Separating Plutonium from Impurities." U. S. Patent 2,813,004 (Nov. 12, 1957).
137. Walsh, K. A., "Extraction of Americium Nitrate with Tributyl Phosphate." U. S. Atomic Energy Comm. Rept. LA-1861 (1955).
138. Walter, L., "Radioactive Effluent Disposal." *Mech. World and Eng. Record*, **138**, 34 (1958); *Battelle Tech. Rev.*, **7**, 304 (1958); *Pub. Health Eng. Abs.*, **38**, 11, 21 (1958).
139. Watson, C. D., Hoiberg, A. J., and West, G. A., "Asphalt Lining of Radiochemical Waste Storage Basins." *Ind. Eng. Chem.*, **50**, 8, 87a (1958).
140. Watson, L. C., Rae, H. K., Durham, R. W., Evans, E. J., and Charlesworth, D. H., "Methods of Storage of Solids Containing Fission Products." Rept. CRCE-736, Atomic Energy of Canada Ltd. (AECL-649) (June 1958); *Nuclear Sci. Abs.*, **12**, 13909 (Oct. 31, 1958).
141. Werner, L. B., and Hill, O. F., "Metal Recovery Process." U. S. Patent 2,815,265 (Dec. 3, 1957).
142. White, J. M., and Lahaie, G., "Ultimate Fission Product Disposal. The Disposal of Curie Quantities of Fission Products in Siliceous Materials." Chalk River Project No. 391 (1957) Atomic Energy Canada Ltd.; *Chem. Abs.*, **52**, 17997 (1958).
143. Whitman, A., and Porter, E. S., "Chemical Stream Pollution From Uranium Mills." U. S. Atomic Energy Comm. Rept. WIN-99 (June 13, 1958).
144. Wibbles, H. L., and Miller, E. I., "Purification Process." U. S. Patent 2,819,944 (Jan. 14, 1958).
145. Wieselberger, F., "The Waste Water Problem at the Munich Research Reactor." *Gas- u. Wasserfach.* (Germany), **98**, 1245 (1957); *Water Poll. Abs.* (Brit.), **31**, 1457 (July 1958).
146. Wolter, F. J., and Diehl, H. C., "Plutonium Compounds and Process for Their Preparation." U. S. Patent 2,819,280 (Jan. 7, 1958).
147. Wymer, R. G., "Fused Salt Processing: Tentative Flowsheet." U. S. Atomic Energy Comm. Rept. CF-56-5-19 (1957).
148. Zeitlin, H. R., and Ullmann, J. W., "Radioactive Waste Economics: Optimum Storage Time Prior to Shipping to Disposal Site." U. S. Atomic Energy Comm. Rept. CF-55-10-101 (Oct. 24, 1955).

32ND ANNUAL MEETING IN DALLAS, OCTOBER 12–15, 1959

Preparations are well along for the 32nd Annual Meeting of the Federation of Sewage and Industrial Wastes Associations, October 12–15, 1959, with the Texas Water and Sewage Works Association as host, at the Statler Hilton Hotel and the Dallas Memorial Auditorium in Dallas, Texas.

Within the outstanding technical program will be sessions on:

1. Sewage works management.
2. Maintenance forum—treatment plant, and sewer.
3. Industrial wastes forum.
4. Operators forum.
5. Symposium on industry—municipality cooperation.
6. Research symposium.

The Federation, the Texas Water and Sewage Works Association, and the Water and Sewage Works Manufacturers Association look forward to welcoming a large and enthusiastic group and promise the trip to be well worthwhile.

Watch the JOURNAL in July for later announcements.

Sewage Works

STATE RESPONSIBILITY FOR COST REDUCTION IN WASTE TREATMENT FACILITIES*

By Walter W. Saxton

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This is one of four papers collectively forming a sewage treatment cost reduction symposium. The papers on activated sludge and digester processes and sewage treatment plant construction have already been published in This Journal (**31**, 4, 399; **31**, 4, 406). The fourth paper, on reduction of operating costs, appears on p. 753 of this issue.

At the present time, five out of every six states are exerting a significant measure of control over design of sewage and industrial waste treatment works. Under these circumstances the state agency becomes more than just a balance wheel between research and development and practice. Its activities may serve either as a stimulant or a deterrent to the application of new methods designed to lower the cost of treatment. The extent to which the agencies are effective depends on many factors: (a) state water resource policy, (b) the legislation and appropriations under which the agency functions, (c) the relative abundance of surface water under its jurisdiction, and (d) the individuals immediately responsible for administering the agency's program.

State regulatory agencies differ in many ways. Washington is one of the few states which has a water pollution control agency administratively separated from the health agency. An agency created for this function alone differentiates between the protection of people, which is a public health agency responsibility, and the protection of water for its diverse uses—many of which have no direct correlation with public health.

In discussing the role of the state agency and its effect on the over-all cost of sewage treatment, it seems logical to consider the subject in terms of four general phases: (a) promotion, (b) preliminary engineering, (c) design and construction, and (d) operation. These phases will be discussed in that order.

Promotion of the Project

Motivating a city or town to action on a sewage treatment problem is usually, although certainly not exclusively, a function of the state agency. This process may take only a few weeks or it may take several years. One thing which can be said of the process, however, is that it costs the town little or no money. It is therefore not considered as part of the cost of treatment in the sense that the

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

term is used here. Promotional and correlated educational activities are a very real item, however, in developing the agency's budget.

Preliminary Engineering

Assuming the successful conclusion of the promotional or motivating phase, the procedure from this point with the smaller communities is likely to be as follows:

1. The engineer negotiates with the city to prepare a preliminary report at a fee of somewhere between $500 and $1,000, said sum to apply toward the total engineering fee if the project is built.
2. Upon the signing of a contract, the job is turned over to a project engineer who becomes responsible for staying within a budget, seldom set higher than the stated fee for the report.
3. The first step the project engineer takes is to write to the state regulatory agency asking for information on the degree of treatment required for the community's sewage.
4. Readily available data (meteorological, hydrographic, population, existing facilities, and financial status), which are already assembled and tabulated, are obtained.
5. "Educated guesses" are made where no information on essential items of consideration is available.
6. The process of assembling a report begins.

The resulting document is essentially a feasibility report but, when it is completed, it is often submitted to the town and the state agencies as a document from which design for construction will be done without further field study.

It is surprising and disappointing to note that adequate collection and analysis of field data are the exception rather than the rule. There can be no serious disagreement with the contention that a thorough field study, which develops accurate and reliable data on all pertinent factors, can eliminate initial overdesign or underdesign—either of which will result in increased costs in the long run. Adequate preliminary engineering also allows for the most economical staging of subsequent expansions. Yet the present system, which encourages an engineer to give a low flat price for an engineering report, does not foster an adequate field engineering study. This situation is due partly to the lack of readily available funds in the majority of communities desiring to initiate a project of this type. Of the 159 municipally owned sewage treatment plants in the State of Washington, 120 serve communities of less than 5,000 people and more than 90 of these serve towns of less than 2,500 population. Without doubt the engineer frequently expects to lose or, at best, break even at this stage of the project. He is willing to accept a low fee in order to get his foot in the door to keep it open. The responsibility for this unfortunately typical situation must be shared by the engineer, the owner, and the state agency. Its correction is not simple. It is only too true that a firm which submits a realistic engineering proposal, based on anticipation of a thorough field study program, simply does not get the job.

The engineering report is the most important phase of the project and its cost should be based on the actual amount of engineering investigation needed to establish the facts. The community which requires an engineer to set a fee which will look attractive to a budget-conscious city council is short-changing itself. What appears to be a saving in engineering costs can, in fact, cost a community a great deal of money in the long run. This is not an acceptable means of reducing the cost of sewage treatment.

Design and Construction

The Engineer's Responsibility

The engineering study must establish the following facts: (a) design population or flow, (b) degree of treatment to be provided, (c) type of treatment, (d) plant site, and (e) the fact that the needed project is financially feasible. The project engineer then turns to the design standards, or guides, published by the state agency. He is indeed fortunate if the guides are considered in proper perspective by both the state agency and himself. Design guides should not be regarded as a crutch or as a strait jacket. Their function is to establish, for the design engineer's advance information, that which is readily acceptable. It remains the consulting engineer's responsibility to use ingenuity and imagination in designing the most economical facility which will adequately meet the set of conditions presented. Design guides should not be so completely detailed and so meticulously enforced as to discourage application of new developments and ingenuity to the utilization of an old and reliable principle or process. The extent to which both the design engineer and the state agency adhere to this philosophy materially influences the rate at which new developments resulting in sewage treatment economies are translated into construction.

Agency Approach

The quality of the engineering, and thus the probability of an economical and effective project, is directly proportional to the degree of responsibility placed on the consulting engineer. However, the state agency has a proper responsibility, since most sewage treatment projects are financed by public funds, to protect a public resource. The control agency, in reviewing plans and specifications for approval, acts most often in the direction of making additional requirements rather than in making deletions. Unfortunately this does not result in a reduction in the bid price on the treatment project. However, it must be remembered that, unless the project accomplishes its objective, its value is seriously reduced regardless of the cost.

One project for a federal installation which was submitted for review showed a weir overflow rate of seven times the conventional rate for primary clarifiers. The State of Washington Pollution Control Commission objected, pointing out that suspended solids reduction would not be adequate for this primary plant. The inclusion of "H" weirs undoubtedly increased the construction cost but it also reduced the chlorine cost which, on a 7-mgd plant, amounted to a significant item. Based on what were admittedly theoretical calculations, a net economy was achieved and a better effluent produced.

While it is not the primary responsibility of the state agency to review plans for economy of design, it is appropriate for an agency to question, occasionally, features which appear unnecessary. For example, the Washington Pollution Control Commission, a few years ago, refused to approve a treatment plant preliminary design, based on a population of 2,000, for a community of 775 people. The location of the community, its potential for growth, and its population history indicated that a 1980 population of 1,000 was an optimistic prediction. This town had not previously had sewers, so actual flow measurements were not possible. In final design a much lower design capacity than that proposed was used. The plant is now in operation with a substantial savings in initial cost based on the engineer's estimate. It was not difficult to convince the town council that, if their dreams of the town's growth materialized and expansion of the plant was

necessary, the added population would provide the needed finances.

Recently, a contractor installed nonstandard (by United States practice) voltage motors in a plant, having convinced the city that it could save a few dollars by purchasing equipment built by a foreign manufacturer. Under the "or equal" clause of the specifications there was little doubt that the equipment would do the job, so the engineer approved the equipment. All went well until a motor burned out. A canvass of suppliers disclosed that neither replacement parts nor a new unit could be obtained except direct from the factory. The city is now investigating the cost of changing to standard equipment.

Communities closely situated, often with contiguous boundaries, naturally develop rivalries. Sometimes these rivalries preclude cooperative effort in solving municipal sewerage problems, even though each community suspects that a joint effort would be mutually beneficial and result in savings to both. It is unlikely that a consulting engineer would run the risk of alienating a client by seriously promoting a joint project against city council resistance. In such instances a state agency can, and often does, propose that a feasibility study, at least, is justified. The Washington cities of Olympia and Tumwater now use a single sewage treatment facility as a result of such a feasibility study.

In another instance a large state institution was faced with the necessity for expanding and modernizing its treatment plant. At the same time a community two miles away was planning to provide treatment for its sewage discharge. Surprisingly, the resistance to a joint project feasibility study came from the institution. The feasibility study showed that, by cooperating with the city, the institution could save annually enough to finance other much needed utility expansion and improvements. A similar joint problem was solved by reversing this procedure. A large state institution and an adjacent sewer district developed a joint project whereby the institution provided treatment capacity in its new plant for the sewer district.

The growing acceptance of sewage stabilization lagoons is no doubt depressing to the sewage treatment equipment manufacturers. However, from an economics standpoint, the lagoon method, where applicable, is proving to be quite satisfactory. For many years, no one seriously considered lagoons for the more humid climate of the Pacific states, particularly for the areas west of the Cascade Mountains. It was considered to be quite a gamble when the first sewage stabilization lagoon in the State of Washington was built in 1954. It worked so well, however, that five more were approved and built in the next three years. In 1958 five more lagoons, the largest one 40 acres, were completed or placed under construction. In addition, construction plans are underway on seven more, the largest using a multi-cell design covering approximately 200 acres for a population of 40,000. The average construction cost of all Washington lagoons in operation, or under construction, is $15.20 per capita. In the State of Washington the average cost per capita over a five-year period was $35.00 for conventional secondary treatment and $15.90 for conventional primary treatment.

Is there a positive approach the state agencies can take toward the problem of reducing sewage treatment costs? Obviously the answer is not to dissect each set of plans with this purpose in mind. The agency's influence should be exerted primarily before the design for a specific project gets to the drafting board.

State regulatory agencies can set up procedures and make budget provisions for the express purpose of study-

ing and evaluating important new developments, either in processes or equipment. The control agencies are sometimes reluctant to give approval to new developments until volumes of supporting and operation data are available. This attitude, while understandable, is not necessarily an indication that the best interest is served, all factors considered. A first-hand observation by an experienced engineer of the development in full-scale operation, and discussion with those actually operating the facility, can establish the control agency's confidence in the development without waiting for the years of operating results.

The state agencies can, by policy and action, help bridge the barriers posed by political boundaries of subordinate governmental units. They can also help by promoting consolidation of utilities when such action appears to be in the best interest of economy of construction and more efficient operation.

Plant Operation

Probably the greatest failure in the entire process takes place at the operation level. A fine spirit of enthusiasm is usually generated in those who participate during the promotion and construction stages of a project. Unfortunately this is very frequently lost when the facility passes into the subsequent stage of routine operation. The operator, the engineer, the city officials, and the state agency must all bear part of the responsibility for this failure. An operator, with increased experience, should be able to improve sewage treatment plant performance but observation, in far too many cases, reveals that the reverse is actually true. The state agency, with usually limited personnel resources, cannot meet this problem solely through visits to the sewage treatment plants. In the State of Washington at the present time there are, in addition to 159 municipal sewage treatment plants, 44 plants which are treating the sanitary sewage from institutions, large industries, and government projects. The best that the state agency can do under these circumstances is to average two visits per year of a type which permit the agency engineer or technician to spend a half day or more at the plants instructing the operator.

One of the technicians on sewage treatment plant operation in the Washington Pollution Control Commission was formerly chief operator of a plant serving a city of 13,500. The following are excerpts from field reports on his visits to neglected plants.

1. City of 1,000 population, visit made at operators' request after return of chlorine machine sent to the factory for repair:

> I explained the use and operation of the machine while reconnecting the unit. It was found that the hard rubber "head" on the machine had been broken at the factory. Temporary repair was made. It was then found that the distribution line from the machine was completely clogged and also broken. After some effort the break was dug out and located. . . . Repair was made and the distribution hose freed of dirt and scale. . . . The machine was then finally placed in operation. . . . Several years before, the machine had clogged from lack of maintenance and cleaning, so it was secured and left to stand.

2. Routine visit to plant serving town of 750 population:

> A tour of the plant indicated some laxity. This was explainable, in part, by the fact that the City and State Highway Department were repaving . . . streets about town and the operator had to spend most of his time watching the street crews so they would not fill the sewer manholes with gravel and asphalt. Other than this, the only problems encountered were the inability to keep bearings and pump shafts on . . . pumps and a scum buildup in the digester due to insufficient heat.

3. Visit to a plant serving 1,650 population:

> . . . a return visit was made to the . . . sewage treatment plant. After some searching, located the operator. He had been put on a street repair job, part time, to replace a man who was on vacation. It was somewhat discouraging to note that even street repair work is put before good or adequate sewage treatment plant operation.
>
> In talking with the operator it was learned that the recommendations made quite some time ago were not used because of the extra hour or so that would have had to be spent at the plant for additional digester recirculation and the added expense of raising the digester temperature from the low 70's to within the area of 90°F.

4. Return visit to a plant serving 500 population:

> A new . . . chlorinator replaced the original machine which had been nearly eaten away due to lack of maintenance and repair. I assisted the operator in adjusting the machine to a proper residual and distribution as the original settings placed all chlorination to the headworks, thus nearly sterilizing the clarigester and thoroughly cleaning the trickling filter. The prechlorination was secured and readjusted to post chlorination.

The above excerpts demonstrate the usual way in which the smaller communities "economize" on their sewage treatment expense. The fallacy of such economy is painfully evident when it becomes necessary to replace equipment which breaks down or becomes completely useless due to neglect. In its sewage treatment plant, most small towns have one of its largest, if not the largest, single investment in a public facility. And yet, all too often, the attitude toward this vital utility could be best expressed by erecting a headstone at the sewage treatment plant gate reading, "Here lies our town's greatest responsibility and investment—may it rest in peace."

Suggestions

The following are suggestions on the practical steps which may be taken by the various interests with direct responsibilities for sewage treatment to influence favorably the over-all cost of such treatment.

For the State Agency

1. Design guides should not be considered in the same sense as regulations, and constructive criticism from engineers, equipment manufacturers, and operators should be welcomed. Revisions should be thoroughly discussed with these interests before adoption by the state agency.

2. There is need for clear information, readily available to municipal officials, on selection of an engineer. The state agency should work with the consulting engineers, possibly through their professional society, to develop an instruction manual designed specifically to fill the municipal officials' need for guidance.

3. Treatment needs, above a set minimum standard, should be determined in each case by first establishing the quality requirements of the receiving water rather than by setting an arbitrary degree of treatment.

4. Monetary assistance by the state during the preliminary engineering phase should be promoted.

5. Continued emphasis on operator training is essential.

For the Consulting or Design Engineer

1. Design criteria should be developed from thorough field engineering conducted over a sufficient time to establish seasonal variations.

2. An operation manual should be prepared for each plant. It should contain daily operation procedures, an equipment maintenance schedule for all plant equipment, a set of "as built" drawings of the plant, and the expected effluent characteristics.

3. Contact with the plant's operator and plant operation should be maintained after the engineering fee has been banked.

For City Officials

1. Adequate protective ordinances covering sewerage and sewage treatment should be adopted.

2. The sewage treatment plant operator should be sent, at the expense of the city, to short schools and other outside training functions. The know-how he gains can save money for his employer.

3. Periodic reports to the city governing body on sewage treatment plant operation and costs should be required.

4. Adequate operator time at the sewage treatment plant should be provided.

For the Operator

1. The conditions which are to be maintained in the receiving water and the required sewage treatment plant effluent characteristics should be thoroughly understood.

2. A record of costs on all plant operations should be kept. An annual summary of such costs is invaluable to the city when preparing its budget.

3. Activities which bring operators together, such as operator sections of sewage and industrial wastes associations, are valuable to the operator and he should participate when possible. State certification, if offered, should be worked toward.

4. Help should be called for when needed—from the employer, the state agency, and from other operators. If an operator cannot repair a piece of equipment himself, he should get help from someone who can.

5. The operator is responsible, to a large degree, for one of his city's major investments. Total sewage treatment costs depend, to a considerable extent, on him and he should recognize this responsibility.

CORRECTION

In the paper, "Comparisons of Short-Term with 5-Day BOD Determinations of Raw Sewage," by H. E. Orford and F. E. Matusky (THIS JOURNAL, **31**, 3, 259; Mar. 1959), Table IV was omitted. The text references to Table III on page 265 should have been made to Table IV, which is given below.

TABLE IV.—Observed and Computed Ratios of Short-Term BOD to 5-Day BOD

Days	Temp. (°C)	Observed Ratio of Short-Term BOD to 5-Day BOD (per cent)	Computed Ratio of Short-Term BOD to 5-Day BOD* (per cent)	Observed Ratio of 5-Day BOD to Short-Term BOD	Computed Ratio of 5-Day BOD to Short-Term BOD
1	20	47.4	46.8	2.11	2.16
2	20	68.8	69.4	1.45	1.44
3	20	82.0	82.6	1.22	1.21
4	20	—	92.0	—	1.09
5	20	100.0	99.3	—	—
[1	37	69.4	69.4	1.44	1.44
2	37	92.3	92.0	1.08	1.09

* According to Equations 5 and 6.

SOME CHARACTERISTICS OF ANAEROBIC SLUDGE DIGESTION

I. EFFECT OF LOADING

By Lee E. Mueller,* Ervin Hindin, Jesse V. Lunsford,† and Gilbert H. Dunstan

Respectively, Research Assistant, Assistant Sanitary Chemist, Assistant Sanitary Engineer, and Head, Sanitary Engineering Section, Division of Industrial Research, State College of Washington, Pullman, Wash.

An extensive amount of research work relative to the anaerobic digestion of raw sludge has been carried out in the last fifty years. The early experimental work on the problem of digestion was done primarily with batch type pilot units. Although the work indicated the complexity of the process, certain basic principles were recognized, among which were the presence of the various phases of digestion, the postulates of some of the mechanisms of digestion, and the identification of some important groups of microorganisms (1) (2) (3) (4) (5) (6).

With the application of the radioactive tracer technique to the study of microbial metabolism, the exact mechanisms of the relatively simple intermediate products of digestion were definitely established (7) (8) (9) (10) (11) (12) (13). The last ten years have seen great strides in the isolation and identification of the more important microorganisms associated with the digestion process (14) (15) (16) (17).

Changes have taken place in the design of the anaerobic digestion unit, since the innovation of treating sewage solids separately. The changes and refinements were directed to produce more optimum conditions for digestion. Along with the alteration in design, new operational concepts have been introduced, such as the value of mixing, mode of mixing, value of high-rate digestion, and the use of prethickened sludge (18) (19) (20) (21) (22) (23).

Problem

It is recognized that the anaerobic digestion of sewage solids is a complex phenomenon. The heterogeneous nature of the raw sludge and mixed bacterial population has prevented a complete understanding of the factors influencing digestion. This investigation is to determine the effect of one of these factors, rate of loading, on the anaerobic digestion process of raw sludge.

Experimental Apparatus

This study was carried out in duplicate with two laboratory digesters operating under identical conditions. Two 12-l glass round-bottom flask digesters were immersed in a 37°C water bath as illustrated in Figure 1. The gas evolved by the digesting material was collected in a brine displacement-type gasometer. Although mixing facilities were provided for in the design, the digesters were used as single stage non-mixing type units after the first 27 wk. The results during this preliminary study are not reported.

Experimental Procedure

Ten liters of digesting sludge obtained from the primary digester at the

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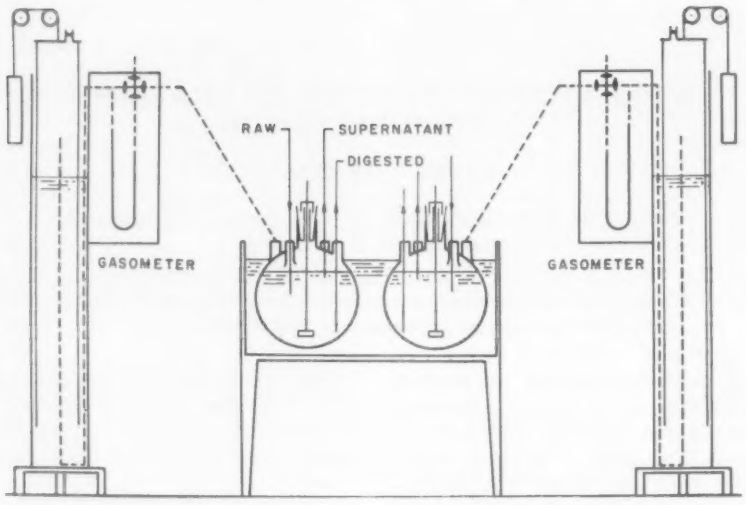

FIGURE 1.—Schematic diagram of laboratory digestion equipment.

Pullman, Wash., sewage treatment plant were placed in each of the two experimental units. One-half of the computed volume of raw sludge for a detention time of 33 days and a loading of 0.05 lb of volatile solids per cubic foot of digester capacity per day was added initially. The volume was gradually increased so that after six weeks the digesters were being fed the computed volume of raw sludge. After the digesters had reached a point of steady state the supernatant, the digested sludge, and digester gas were routinely analyzed for their chemical characteristics.

A detention time of 33 days was maintained throughout the study. The rates of volatile solids loading selected for study were 0.05, 0.075, 0.10, 0.11, and 0.135 lb/day/ cu ft of digester capacity. In order to obtain these loading rates and yet maintain the detention time constant the feed had to be diluted for volatile solids loadings of less than 0.075 lb/day/cu ft of digester capacity or concentrated by centrifuging for loadings in excess of this level. Gravity feeding was employed when the raw sludge contained less than 8 per cent total solids. Force feeding was necessary when the solids content exceeded 8 per cent.

The digesters were fed daily and the resulting supernatant overflow collected for the following tests: pH, alkalinity, volatile organic acids, and suspended solids. The pH and alkalinity were determined daily using an automatic titrator. The suspended solids were determined weekly. Separation of the volatile acids was facilitated by using partition chromatographic procedures devised by Bulen *et al.* (24) and modified by Teletzke (25) and by Mueller *et al.* (26). The volume of the digester gas was measured daily prior to feeding. The per cent of carbon dioxide in the gas was determined weekly using an Orsat type instrument. The total and volatile solids of the raw and digested sludge were determined weekly. All chemical analyses were carried out according to the procedure of "Standard Methods" (27), with the exception of the volatile acids separation and determination which used methods developed by others (23) (24) (25).

The feed consisted of solids settled

from the raw sewage and from the cellular material sloughed off a high-rate trickling filter at the municipal sewage treatment plant. The raw sludge was a true domestic sludge as the community does not possess any industrial establishments.

Raw sludge was obtained weekly. Since sludge is a heterogeneous mixture of settleable sewage solids and associated microorganisms, it is probable that the nutritional composition of the feed was not always the same even though the volatile solids remained the same. The raw sludge obtained contained at least 5.4 per cent total solids of which 75 per cent were volatile. Analyses of the dried raw sewage solids on two occasions compared well with Neave and Buswell's earlier work (1) as shown in Table I.

Analysis of the raw sludge refrigerated at 4°C showed no change in the volatile solids content and pH, and little in the alkalinity; but a noticeable increase in the volatile acids content occurred after seven days.

Mathematical Consideration

The data obtained from the digesters were studied to determine the justification of considering the values as from a single source. Both digesters were started with the same seed materials, daily feedings were from the same lot of raw sludge, and the digesters were subjected to identical sampling procedures. It was thought that the data would be identical for each, within the limits of experimental error. The statistical methods applied indicated that this assumption was correct and that the data be regarded as obtained from a single source. The data presented in the following illustration and tables are average values of the chemical indices of particular constituents of the digesting material at specific loadings. The averaged values are results of data obtained over a minimum period of five weeks.

Discussion

The digesters were initially operated at the rate of 0.050 lb of volatile matter per cubic foot of digester capacity per day. The supernatant liquor was a milky white liquid having the following characteristics: suspended solids of 400 ppm, total alkalinity of 4,121 ppm as $CaCO_3$, pH of 7.39, and total volatile acids of 330 ppm as acetic acid. The quality and quantity of the gas produced was as follows: total gas production of 0.458 cfd, or 9.33 cfd/lb of volatile material added, and the carbon dioxide content of the gas was 30 per cent. The digested material contained 37 per cent volatile matter. The digesters were obtaining an average of 77 per cent reduction in volatile solids. The digested material had the characteristics of a relatively stable inoffensive sludge.

With an increase in the loading rate, a change in the chemical characteristics was anticipated. Mechanisms of bacterial metabolism and the ability of the microorganisms to grow in an altered environment must be considered in evaluating the changes in the magnitude of the chemical characteristics. An increase in the feeding rate is an increase in food supplied for the digester flora. Unstable conditions will exist until the microorganisms have become fully adapted to their new environment or a modification of the environment would have taken place. Such conditions may bring about an increase in the microbial population

TABLE I.—Comparison of the Composition of Individual Samples of Dried Sewage Solids With That of Other Published Data

Dried Solids Source	Analysis (per cent)		
	Protein	Grease	Crude Fiber
Neave and Buswell (1)	19.4	25.2	11
Raw sludge lot 100	22.5	10.9	21.4
Raw sludge lot 147	20.3	12.5	23.7

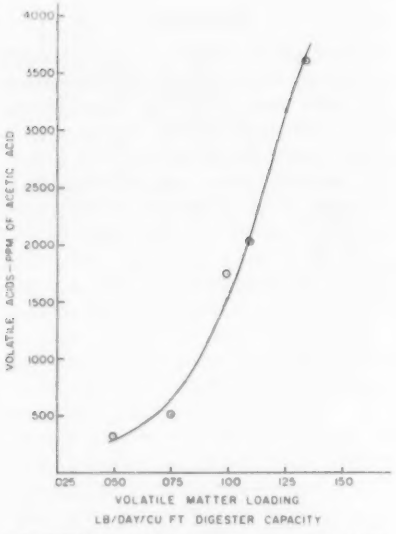

FIGURE 2.—Relationship of total volatile acids to volatile matter loading.

and/or initiate an environmental selection of the more compatible microorganisms.

Accompanying an increase in loading rate was an increase in bacterial ac-

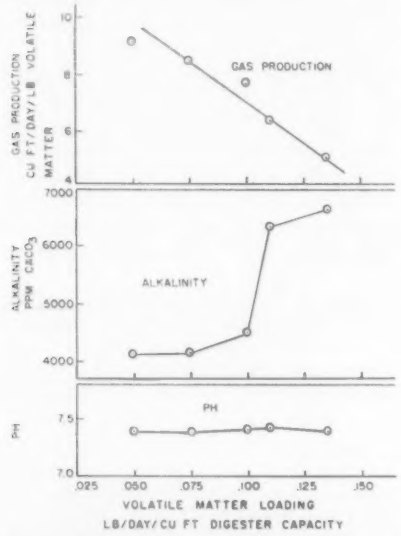

FIGURE 3.—Relationships of chemical characteristics to loading level.

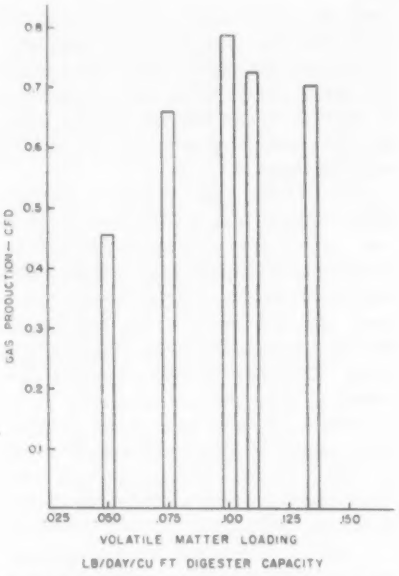

FIGURE 4.—Relationships of gas production to loading level.

tivity. The volatile organic acids, an intermediate product of anaerobic metabolism of all digestible organic solids, increased with an increase in loading, as illustrated in Figure 2. Other intermediate products of digestion also increased. The alkalinity increased as the loading level increased as shown in Figure 3.

If the production of substances causing alkalinity is in balance with the volatile acid production and the buffering capacity is not seriously affected, there should be little or no change in the pH. This was verified as illustrated in Figure 3.

With an increase in the intermediate products, an increase in the final products occurred. This will happen if there is not a formation of toxic material or an accumulation of inhibitory substances. Total gas production increased until the volatile solids loading in the digester reached 0.11 lb/day/cu ft, thereafter gas production decreased as shown in

Figure 4. It has been known that a volatile organic acids concentration above a certain level will inhibit the activity of certain gas producing organisms. In this study, the inhibition occurred when the rate of feeding volatile matter to the digester reached 0.11 lb/day/cu ft, at which time the volatile acid concentration was 2,028 ppm of acid as acetic acid. Another factor which may have affected the gas production is the relative rates of growth of the various groups of microorganisms under the prevailing conditions.

A rise in the carbon dioxide content occurred as the rate of loading increased as shown in Figure 5. However, the increase in the carbon dioxide content may not have been caused directly by the increased volatile acids content. If, however, there is a rise in the volatile acid content without an equivalent rise in alkalinity, the excess acid will react with the buffering system. As the bicarbonate ion is a major constituent of the buffering system, the neutralization of the acid will produce carbon dioxide as one of its products. Assuming the digesting liquid is saturated with carbon dioxide, the excess carbon dioxide will enter into the gas storage cylinder.

Mueller *et al.* (26) have shown the presence of butyric, propionic, acetic, pyruvic, formic, and the lactic-succinic acids. Teletzke (25), using a slightly different modification, was able to separate butyric, propionic, acetic—pyruvic group, formic, succinic, and lactic acids.

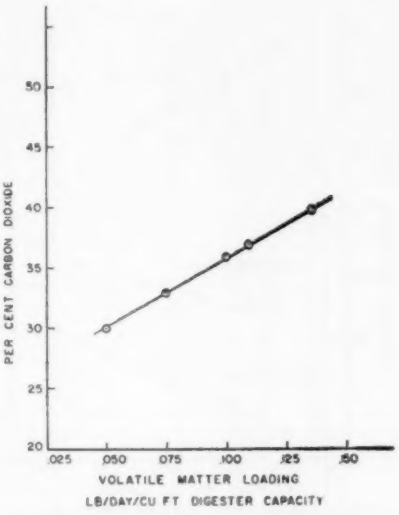

FIGURE 5.—Carbon dioxide content of gas at various digester loading levels.

In both investigations it was found that butyric, propionic, and acetic acids were in preponderance during normal digestion of sewage solids. This was verified by the data of Table II. The three major acids exceeded 96 per cent of total acids present. Stadtman and Barker (8) (9) (10) have shown that methane may be formed either by the reduction of carbon dioxide by hydrogen or the anaerobic digestion of acetic acid. The mode of methane production will depend on the microorganisms present and the type of digestible organic material available. They have also shown that if carbon dioxide is present in the solution, the

TABLE II.—Distribution of Component Volatile Acids for Various Volatile Matter Loadings

Volatile Matter Loading in Digester (lb/day/cu ft)	Butyric Acid (per cent)	Propionic Acid (per cent)	Acetic Acid Group (per cent)	Formic Acid Group (per cent)	Lactic Acid Group (per cent)
0.05	4.45	23.03	68.90	1.73	1.82
0.075	10.02	25.29	63.01	0.87	0.79
0.10	12.44	29.73	58.38	0.40	0.27
0.11	14.36	29.83	55.39	0.22	0.20
0.135	19.72	32.50	47.32	0.28	0.18

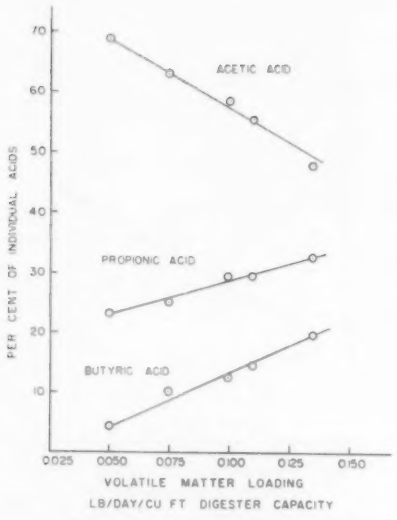

FIGURE 6.—Component volatile acid relationship at various digester loading levels.

microorganisms will produce a gas with a higher methane to carbon dioxide ratio from propionic or butyric acid than from acetic acid. As the loading level increased, a change in the distribution of the component volatile acids occurred as shown in Figure 6. This occurrence indicated that the rate of metabolism of propionic and butyric acids was less than their production while the rate of metabolism of the acetic acid had surpassed its rate of formation. It was anticipated that a digester gas of a higher carbon dioxide content would be produced with an increase in total volatile acids and a decrease in the relative amount of acetic acid. Experimentally, this occurred at each increased loading rate.

Since the gas production per unit feed per day decreased linearly at increased loading rate according to Figure 4, a decrease in the quality of the digested sludge, was anticipated. Table III shows that an increase in the volatile solids of the digested sludge did occur.

The efficiency of the digester as measured by the per cent reduction in volatile solids was expected to decrease with increased loading rates. There are variables other than the gas production per unit feed per day which affected the digester efficiency. One of these factors is the quality of the supernatant overflow. There was approximately a 180-fold increase in the suspended solids in the supernatant as the volatile solids loading increased from 0.05 to 0.135 lb/day/cu ft of digester capacity. This is shown in Table III. A large amount of digestible material would be removed by way of the solids in the supernatant. The actual quantity of solids being digested is somewhat less than the amount computed for the specific rate.

Figure 7 shows the relationship between volatile solids loading and per cent reduction in volatile solids in the digester. The rate of reduction begins to fall off sharply as the loading increases beyond 0.100 lb/day/cu ft of digester capacity. There appears to be a practical limit to the degree of digestion of a particular sludge. The maximum loading level at which this limit is reached may be regarded as the critical loading level from which maximum reduction in the volatile solids may be obtained.

Such factors as increased suspended solids in the supernatant, practical limit of sludge digestion, and quantity of gas per unit feed per unit time will have an effect on the degree of reduction of volatile material the digester can obtain.

TABLE III.—Solids Content of Various Constituents of Test Digester

Volatile Matter Loading in Digester (lb/day/cu ft)	Volatile Solids Content of Digested Sludge (per cent)	Suspended Solids in Supernatant (ppm)
0.050	37	400
0.075	39	810
0.100	44	10,620
0.110	46	44,900
0.135	55	71,000

Conclusions

Anaerobic digestion of sewage solids is a complex phenomenon. The heterogeneity of the digestible material and the mixed bacterial population obscures the picture of the individual mechanisms involved. As a result, various chemical tests relative to the simple intermediate and final products of digestion are used as artificial criteria for the evaluation of digester conditions.

This study has shown that not one but many chemical characteristics must be studied for a proper evaluation of digester conditions. All the characteristics are directly or indirectly dependent on the digestible material being fed.

At the present time, the total volatile acids content is considered the most important characteristic. However, the organic acid concentration is greatly influenced by the nutritional composition and the quantity of volatile solids in the raw sludge. The total volatile acid cannot be considered solely, because of the influence of the nutritional composition of the raw sludge and the nature of the industrial waste solids on the quantity and distribution of the potential individual volatile acids. It was found that total volatile acidity in excess of 2,000 ppm as acetic acid will inhibit gas production.

Of greater importance is the volatile acid alkalinity relationship. The volatile acids must be in balance with the alkalinity for normal digestion to occur.

Variation in the pH will occur only after the volatile acidity-alkalinity balance has been destroyed or seriously affected.

An increasing proportion of carbon dioxide in the gas will almost always result from the neutralization of the free volatile acids by the buffering system. The variation of this index of digestion will result just prior to an alteration of the volatile acidity-alkalinity balance.

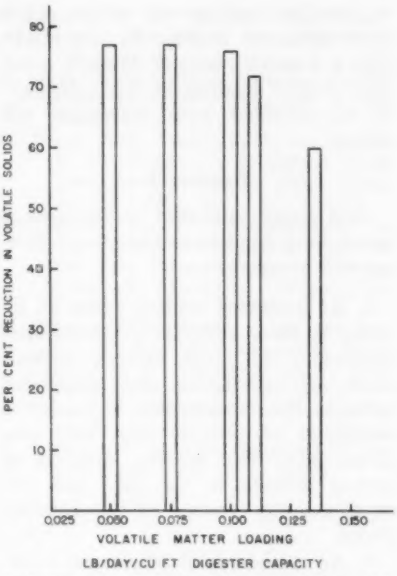

FIGURE 7.—Relationship of volatile solids reduction at various loading levels.

Although very little work has been done with the relationship of the component volatile acids, their relative ratios may aid in a predictive manner. Increasing anounts of butyric and propionic acids with decreasing concentrations of acetic acids were synonymous with decreasing digester efficiency in this study.

The chemical characteristics of the final products such as the volatile solids content of the digested sludge and the gas production must be considered in view of the chemical characteristics of the intermediate products. The relative quantity of volatile material in the digested sludge indicates what the average condition of the digester has been during the detention time of that particular sample of digested material. Gas production is very susceptible to variations even under normal digester operation. However, a continually decreasing gas production indicates decreasing efficiency.

The obvious aim in the operation of a digester is to feed sludge at the high-

est possible loading rate within maximum efficiency limits. In this study, with a detention time of 33 days, a volatile matter loading of 0.075 lb/day/cu ft provided near maximum efficiency.

Summary

This study indicated under normal operational conditions that the following will occur:

1. At increased loading rates, an increase in these chemical characteristics occurred: (a) total volatile organic acids, (b) alkalinity, (c) suspended solids in the supernatant, (d) relative quantities of butyric acid and propionic acid, (e) relative amounts of carbon dioxide in the gas, and (f) volatile solids content of the digested sludge.

2. At increased loading rates, a decrease in the following occurred: (a) gas production per unit of volatile matter added per unit of time, (b) volatile solids reduction, and (c) the relative quantity of acetic acid.

3. Increased loading rates did not affect the pH.

4. Total gas production was inhibited when the total volatile acids were present in excess of 2,000 ppm as acetic acid.

5. A critical loading level exists from which a decrease in loading will have a negligible effect on the per cent reduction of the volatile solids, while an increase in loading will have a marked decrease in the per cent reduction of the volatile solids content.

Acknowledgment

This investigation was supported in part by a research grant from the National Institutes of Health, Public Health Service.

References

1. Neave, S. L., and Buswell, A. M., "Chemical Studies on Sludge Digestion." Circular No. 8, Illinois Water Survey Division (1930).
2. Stephanson, M., "Bacterial Metabolism." Longmans, Green and Company (1930).
3. Buswell, A. M., and Boruff, C. S., "The Relation Between the Chemical Composition of Organic Matter and the Quality and Quantity of Gas Produced During Sludge Digestion." *Sewage Works Jour.*, **4**, 3, 454 (May 1932).
4. Buswell, A. M., and Boruff, C. S., "The Anaerobic Fermentation of Lignin." *Jour. Amer. Chem. Soc.*, **56**, 886 (1934).
5. Buswell, A. M., and Tarvin, D., "The Methane Fermentation of Organic Acids and Carbohydrates." *Jour. Amer. Chem. Soc.*, **55**, 1751 (1934).
6. Buswell, A. M., "Important Consideration in Sludge Digestion. Part II.—Microbiology and Theory of Anaerobic Digestion." *Sewage Works Jour.*, **19**, 1, 28 (Jan. 1947).
7. Buswell, A. M., and Mueller, H. F., "Mechanisms of Methane Fermentation." *Ind. Eng. Chem.*, **44**, 550 (1952).
8. Stadtman, T. C., and Barker, H., "Studies on the Methane Fermentation." *Arch. Biochem.*, **2**, 256 (1949).
9. Stadtman, T. C., and Barker, H., "Studies on Methane Fermentation." *Jour. Bact.*, **61**, 67 (1951).
10. Stadtman, T. C., and Barker, H., "Studies on Methane Fermentation." *Jour. Bact.*, **61**, 1 (1951).
11. Barker, H. A., "Studies on Methane Fermentation." *Jour. Biol. Chem.*, **137**, 1 (1953).
12. Carlson, S. F., and Rubew, S., "Carbon Dioxide Assimilation by Propionic Acid Bacteria." *Proc. Natl. Acad. Sci.*, **26**, 422 (1940).
13. Selwiche, C. C., "Biological Transformation of Nitrogen Compounds." *Ind. Eng. Chem.*, **48**, 1421 (1950).
14. Buck, T. S., Jr., Keefer, C. E., and Hatch, H., "Bacteriological Studies of Sludge Digestion. I. A Facultative Anaerobe Isolated from Digested Sludge." THIS JOURNAL, **25**, 9, 993 (Sept. 1953).
15. Keefer, C. E., Buck, T. C., Jr., and Hatch, H., "Bacteriological Studies of Sludge Digestion. III. Effect of Different Quantities of *Streptococcus diploidus* on Sludge Digestion." THIS JOURNAL, **25**, 12, 1406 (Dec. 1953).
16. Buck, T. C., Jr., Keefer, C. E., and Hatch, H., "Bacteriological Studies of Sludge Digestion. IV. A Motile Facultative Anaerobe Isolated from Digested

Sludge." THIS JOURNAL, **26**, 2, 164 (Feb. 1954).
17. Keefer, C. E., Buck, T. C., Jr., and Hatch, H., "Bacteriological Studies of Sludge Digestion. V. Optimum pH for Sludge Digestion with *Bacillus endorhythmos*." THIS JOURNAL, **26**, 5, 635 (May 1954).
18. Rawn, A M, Banta, A. P., and Pomeroy, R., "Multiple-Stage Sewage Sludge Digestion." *Trans. Amer. Soc. Civil Eng.*, **104**, 93 (1939).
19. Torpey, W. N., "High-Rate Digestion of Concentrated Primary and Activated Sludge." THIS JOURNAL, **26**, 4, 479 (Apr. 1954).
20. Torpey, W. N., "Loading to Failure of a Pilot High-Rate Digester." THIS JOURNAL, **27**, 2, 121 (Feb. 1955).
21. Torpey, W. N., "Concentration of Combined Primary and Activated Sludges in Separate Thickening Tanks." *Proc. Amer. Soc. Civil Eng.*, **80** (Sep. No. 443) (May 1954).
22. Rankin, R. J., "Sewage Sludge Digestion." Dorr-Oliver, Inc. Reprint 39 (1957).
23. Cerny, P. J., "Sludge Digestion Can Be Improved." *Civil Eng.*, **26**, 2, 655 (1956).
24. Bulen, W. A., Varner, J. E., and Burrell, R. C., "Separation of Organic Acids from Plant Tissue." *Anal. Chem.*, **24**, 187 (1952).
25. Teletzke, G. H., "Determination of Organic Acids in Digesting Sludge by Partition Chromatography." Thesis, Univ. of Wisconsin, Madison, Wis. (1955).
26. Mueller, H. F., Buswell, A. M., and Larson, T. E., "Chromatographic Determination of Volatile Acids." THIS JOURNAL, **28**, 3, 255 (Mar. 1956).
27. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).

MEETINGS OF INTEREST

June 15–17 **Sixth Annual Ontario Industrial Waste Conference,** Delawana Inn, Honey Harbour, Ontario. D. S. Caverly, Ontario Water Resources Commission, Parliament Bldgs., Toronto 5, Ont.

June 17–20 **National Society of Professional Engineers,** Commodore Hotel, New York, N. Y.

June 22–26 **Air Pollution Control Association,** Hotel Statler, Los Angeles, Calif. Harry M. Pier, Executive Secretary, Air Pollution Control Association, 4400 Fifth Avenue, Pittsburgh 13, Pa.

June 22–26 **American Society for Testing Materials,** Chalfonte-Haddon Hall, Atlantic City, N. J. Robert J. Painter, 1916 Race Street, Philadelphia 3, Pa.

July 12–17 **American Water Works Association,** Civic Auditorium, San Francisco, Calif. Harry E. Jordan, Secretary, American Water Works Association, 2 Park Avenue, New York 16, N. Y.

July 22–25 **First International Conference on Waste Disposal in the Marine Environment,** University of California, Berkeley 4, Calif.

Sept. 8–10 **Annual Water and Sewage Plant Operators Short Course,** University of Maryland, College Park, Md. W. M. Bingley, 2411 N. Charles Street, Baltimore 18, Md.

Sept. 13–18 **American Chemical Society,** 136th National Meeting, Atlantic City, N. J. R. M. Warren, American Chemical Society, 1155 16th Street, N. W., Washington 6, D. C.

Sept. 20–23 **American Public Works Association,** Olympic Hotel, Seattle, Wash. Robert D. Bugher, Executive Director, 1313 E. 60th Street, Chicago 37, Ill.

FERTILIZING CHARACTERISTICS OF SEWAGE SLUDGE *

By Myron S. Anderson

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Interest in the use of sewage sludge as a fertilizer dates essentially from 1927 when a large activated sludge treatment plant went into operation for the city of Milwaukee, Wis. (1) (2).

The chemical composition and fertilizer value of sewage sludge depend in part on the method of treatment from which the sludge is obtained. Sewage sludge and its relative value as fertilizer may be divided into three groups:

1. Undigested sludge from secondary treatment in general which is of greatest fertilizer value.
2. Digested sludge from primary treatment which is of lower fertilizer value and is often used as a soil conditioner or mulch material.
3. Material prepared from a combination of the two processes which may be a little better than that obtained from primary treatment.

Chemical Composition of Sludges

An approach to the approximate usefulness of these processed sewage materials can best be made by consideration of their chemical compositions and other properties. Table I gives a general idea of the primary fertilizing constituents present in sludges from some different types of plants.

The value of sludge is strongly influenced by its nitrogen content, particularly when the content of this constituent is relatively high as in the case of sludge obtained from activated sludge treatment (3). Nitrification rate is also an important factor, although such a determination is seldom made by fertilizer control officials. Some knowledge of relative nitrification rates is available from the rather scant literature on the subject. Data are given in Table II.

The nitrification rates of activated sludges tend to be about 2½ times those of digested sludges, and the nitrogen contents also about 2½ times as much. If both of these factors are considered, making a resultant factor of 6.25, about the same relative differences are shown as are frequently found in market values.

Table III shows the appreciable increase during a recent 20-yr period in the phosphoric oxide content of sludge from the activated sludge treatment process as evidenced by the increase of P_2O_5 from 3.2 to 5.7 per cent.

The higher phosphate contents are due mainly to two factors: (a) the extensive use of modern phosphatic detergents, and (b) to a lesser extent, inclusion of ground bones and other highly phosphatic residues from home and institutional garbage disposal systems. The nitrogen contents of the two types of sludge have not changed greatly over a period of years.

Minor Elements

A group of minor element determinations for different types of sewage sludges was recently reported (4) (5). Summarized data are given in Table IV.

It is apparent that the minor element

* Presented at the Annual Meeting of the Indiana Sewage and Industrial Wastes Assn.; Indianapolis, Ind.; Nov. 5-6, 1958.

TABLE I.—Chemical Composition of Selected Sewage Sludges

Treatment Plant Location	Source of Sludge	Primary Fertilizing Constituents (per cent)			Ash (per cent)
		Total Nitrogen (N)	Total Phosphoric Oxide (P_2O_5)	Acid Soluble Potassium (K_2O)	
Chicago, Ill.	Activated sludge (undigested)	5.60	6.97	0.56	37.4
Milwaukee, Wis.	Activated sludge (undigested)	5.96	3.96	0.41	27.7
Washington, D. C.	Digested	2.06	1.44	0.14	56.2
Rochester, N. Y.	Digested	2.54	1.16	0.29	42.8
Baltimore, Md.	Digested primary + activated sludge + trickling filters	2.92	2.83	—	—
Des Moines, Iowa	Digested primary + activated sludge + trickling filters	1.81	3.31	0.40	61.4
Anonymous	Imhoff tank sludge	2.54	1.16	0.29	42.8

contents of sewage sludges vary widely. Such variation is not surprising, since materials from various industrial processes find their way into city sewers.

Fertilizer Use

Since sewage sludge is high in organic matter, it may find a place in markets as an organic ammoniate in competition with certain seed meals and pomaces. It is sometimes used as a conditioner for mixed fertilizers, also as a mulch material for horticultural plants, or as a soil conditioner. The nitrogen content and quality essentially fix its value as a fertilizer. The better quality sludge is ordinarily used for turf, home gardens, and specialty crops. However, the relatively low nutrient content of sewage sludge does not permit it to compete with other nitrogen fertilizers if long-distance transportation costs are considered.

Use of sewage sludge as a fertilizer appeals to the limited number of people who believe that chemically processed fertilizers should not be applied to soils, especially where garden vegetables are to be grown. The acreage of land thus involved is presumably not large, and the potential market for sludge to be used in this way not very great.

TABLE II.—Comparison of Nitrification Characteristics of Activated Sludge and Digested Sludge with Ammonium Sulfate

Treatment Plant Location	Source of Sludge	Total Nitrogen (N) (per cent)	Portion of Nitrogen Converted to Nitrate at 30°C at Different Time Periods (per cent)	
			4 Wk	12 Wk
Chicago, Ill.	Activated sludge (undigested)	5.60	42	51
Milwaukee, Wis.	Activated sludge (undigested)	5.96	49	57
Washington, D. C.	Digested	2.06	14	18
Rochester, N. Y.	Digested	2.54	15	23
—	Ammonium sulfate*	20.5	89	90

* Used as a comparison with various sludges.

TABLE III.—Comparison of the Nitrogen and Phosphoric Oxide Content of Activated Sludge and Digested Sludge, 1931–35 and 1951–55

Determination	Activated Sludge		Digested Sludge	
	1931–35	1951–55	1931–35	1951–55
Nitrogen (%):				
Min	4.4	4.8	1.3	1.8
Max	6.4	6.0	3.0	3.1
Avg	6.0	5.6	2.2	2.4
Phosphoric oxide [P_2O_5] (%):				
Min	3.2	4.0	0.8	0.9
Max	3.8	7.4	3.8	5.0
Avg	3.2	5.7	2.1	2.7

About thirty years ago field tests involving the growing of common garden crops were made with sludge from the Baltimore sewage treatment plant (6). These tests showed that sludge applied to soil continued to supply nitrogen to the crop during the second year after application.

Organics have in years past been extensively used by growers of cotton and tobacco. A sizable tonnage still goes to areas where tobacco is grown. It is popular as a carrier of some of the nitrogen used for growing this crop. The tonnage of several organics used varies widely from time to time. Table V illustrates the changes between 1910 and 1950 (7).

Several factors influence the demand for organic ammoniates as fertilizer:

1. Different forms of chemical nitrogen have encroached on the organic field.
2. Higher analysis mixed fertilizers are extensively demanded.
3. Certain organics are sold at a premium as animal feed.

The fertilizer industry cannot successfully compete with animal feeds in this market. Cottonseed meal and fish meal are now widely used as feed; hence, their near disappearance from fertilizer markets. Castor pomace is poisonous when used as feed; hence it is limited to use as a fertilizer.

Sewage sludges first entered the fertilizer markets of the United States about 30 years ago. Sewage sludge consumption as a fertilizer over a period of years is shown in Table VI.

The first reported sale of sludge as fertilizer was in 1927 (4). Activated sludge now has a relatively important place as a material for direct application to soil, as well as a constituent of mixed fertilizer which is used for specific purposes. Digested sludge is used in much smaller tonnage, only a minor portion being used in mixed fertilizer.

Organic conditioners that were extensively used in mixed fertilizers a few years ago are now much less important in the trade. There is now increasing demand for higher analysis fertilizers in pelleted form with organics completely omitted. The demand for organics of low nitrogen content is essentially a local one where the mate-

TABLE IV.—Minor Chemical Elements in Activated Sludge and Digested Sludge

Sludge	Element (ppm)				
	Copper	Zinc	Boron	Manganese	Molybdenum
Activated sludge:					
Min	385	950	6	65	6
Max	1,500	3,650	74	190	45
Avg	916	2,500	33	134	16
Digested sludge:					
Min	315	1,350	4	30	2
Max	1,980	3,700	15	790	12
Avg	643	2,459	9	262	6

TABLE V.—Annual Production and Consumption of Certain Natural Organic Materials During Selected Years 1910 to 1950 in Units of 1,000 Tons

Year	Cottonseed Meal		Castor Pomace		Fishery By-products	
	Production	Consumption as Fertilizer	Production	Consumption as Fertilizer*	Production	Consumption as Fertilizer
1910	1,326	442	17	17	78	80
1920	1,817	447	15	23	121	100
1930	2,232	215	27	40	127	74
1940	1,882	115	58	65	192	34
1950	2,555	60	73	82	240	8

* Consumption in excess of production is accounted for by imported materials.

rials sell at low prices. A few prices at places of production are given in Table VII.

Referring to Table VII, it should not be assumed that the various carriers of nitrogen are of equal value for all purposes. No. 1 is excellent for turf, either for direct application or for use as a constituent of mixed fertilizers. No. 2 is approximately equal to No. 1 as a fertilizer, but is dusty to handle until it is processed with other materials. No. 6 is of slightly higher nitrogen content than Nos. 1 and 2, but the nitrogen quality and usefulness are about the same. Furthermore, for fertilizer considerations No. 6 finds its greatest use in the manufacture of mixed fertilizers. None of these three materials burns plants as readily as does an equal quantity of water-soluble chemical nitrogen. The activated sewage sludges usually are not used on house plants, because of the possibility of development of undesirable odors. No. 3 is sold by the city to a jobber who orders carload lots sent to various mixing plants. A large part of this material presumably serves as a fertilizer conditioner and as a source of nitrogen for tobacco production as well as for other crops where organic forms of nitrogen are particularly desired. No. 6 is formulated especially for use on turf. The nitrogen is of low water-solubility, but is available to plants throughout a growing season.

No. 8 is usually the cheapest form of chemical nitrogen, but presents certain problems of application. No. 9 is widely used as a solid form of chemical nitrogen for direct application to land and in mixed fertilizers. No. 4 is avail-

TABLE VI.—Consumption of Sewage Sludge as Fertilizer in Tons for Stated Years, 1930 to 1957

Calendar Year	Dried Activated Sludge		Dried Digested Sludge	
	As Separate Material	In Mixed Fertilizer	As Separate Material	In Mixed Fertilizer
1930	14,852	17,811	—	—
1940	26,307	78,992	23,000	3,000
1945	29,261	61,306	30,274	5,791
1950	63,366	55,965	30,738	6,581
1953	69,494	—	36,719	—
1957	93,152	—	37,577	—

TABLE VII.—Wholesale Prices of Nitrogen at Points of Production

No.	Material	Approximate Nitrogen Content [N] (per cent)	Price per Pound (cents)
1	Milwaukee sludge	6	35
2	Chicago sludge	5–6	25
3	Baltimore sludge	3	10
4	Washington sludge	2	Free
5	Lancaster, Pa., stockyard manure	1.5	10
6	Cottonseed meal*	6.5	48
7	Urea-form†	38	36
8	Anhydrous ammonia*	82	5
9	Ammonium sulfate, synthetic	21	9

* October 6, 1958.

† Sold under various trade names.

able to anyone who will haul it away. Much of the sludge has been used on turf in park areas.

Sometimes claims are made that the minor element contents of various organics add greatly to their value as fertilizers. As a rule, purchase of undetermined quantities of minor element compounds in indefinite chemical forms is not recommended. Such materials should be used only when the soil is known to be deficient. The quantities of the various minor elements present in sewage sludges are probably seldom toxic to plants. Claims have been made, however, that the zinc content of sludge is sometimes high enough to cause trouble.

Sanitary Status of Sludge

Activated sludge must be heat-treated before it is sold as fertilizer. Digested sludges should be heat-treated or incorporated with soil for several months before application on home vegetables.

Where digestion is provided, as is true at many primary treatment plants, there is the opportunity to utilize some of the gas for heat-treatment of the sludge. In many activated sludge plants where the sludge is dewatered by vacuum filtration prior to heat-drying, no digestion is provided; therefore, fuel is an added cost. However, the nitrogen content of digested sludge is appreciably lower.

Economic Problems

Statistics show a continued increase in the use of activated sludge for direct application to land. It is difficult to predict how much farther the increase can go without material reduction in price. The nitrogen contained in such materials sells much higher than the price of chemical nitrogen.

Digested sludges will no doubt continue to be used locally when the price delivered to the premises is low enough. The quality of the material is often about equal to that of farm manure, which is very cheap at the point of production, but expensive when delivered to town gardeners.

Economic problems can be expected to develop as wider fertilizer use is accomplished. It is important that responsible parties of municipalities, as well as agricultural users, be better informed as to what may be expected from sludge applied to soil. The responses will no doubt vary with type of soil, kind of plants grown, and climatic conditions.

References

1. Cramer, R., and Wilson, J. A., "Scientific Sewage Disposal at Milwaukee." *Ind. Eng. Chem.*, **20**, 4 (1928).
2. Kadish, V. H., "Milorganite—A new Fertilizer Material." *Ind. Eng. Chem.*, **20**, 9 (1928).
3. Anderson, M. S., "Sewage Sludge for Soil Improvement." U. S. Department of Agriculture, Circular 972, 27 pp. (1955).
4. Anderson, M. S., "Comparative Analyses of Sewage Sludges." THIS JOURNAL, **28**, 2, 132 (Feb. 1956).
5. Clark, L. J., and Hill, W. L., "Occurrence of Manganese, Copper, Zinc, Molybdenum and Cobalt in Phosphate Fertilizers and Sewage Sludge." *Jour. Assn. Offic. Agr. Chemists*, **41**, 631 (1958).
6. Keefer, C. E., and Armeling, G. K., "Fertilizing Value of Baltimore Sewage Sludge." *Eng. News-Rec.*, **101**, 837 (1928).
7. Mehring, A. L., Adams, J. R., and Jacob, K. D., "Statistics on Fertilizers and Liming Materials in the United States." U. S. Department of Agriculture, Statistical Bulletin 191, 182 pp. (1957).

THE EFFECT OF SEWAGE TREATMENT ON VIRUSES

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Increasing population density will intensify the treatment problems associated with sewage. While present sewage treatment practices, based largely on empirical standards, are apparently sufficient to make recognized outbreaks of water-borne disease a rarity in the United States, future demands on water supplies and uses of sewage may require a more flexible role for sewage treatment products. From a sanitary standpoint, the use of effluents and sludge should be preceded by the assurance that they are not harmful. The disinfecting action of chlorine on bacteria in sewage has received attention from many and has resulted in a general feeling that effluents in contact with 0.5 ppm combined residual chlorine for 15 min are free of pathogenic bacteria and protozoans (1). Endamebic cysts, however, are known to require more intensive treatment than coliform bacteria (2). Knowledge of the destruction of viruses by sewage treatment is limited to laboratory observations and to a very few plant studies. The work described here was undertaken to determine the types of sewage treatment that destroy viruses under operating conditions.

The many isolations of viruses from sewage since bacteriophage (3) and poliovirus (4) were recognized as enteric agents were made chiefly for identification purposes or were associated with outbreaks of disease or were done for locating the source of infection. The question of destruction of virus by sewage treatment so far has stimulated little effort. Gear noted early (5) that poliovirus was still present after settling in both the effluent and sludge, that humus tank effluent contained virus, but that final sand filtration and digestion of sludge destroyed it. Mack *et al.* (6) find that activated sludge treatment removes viruses but not completely, and there have been indications (7) that neither primary nor secondary treatment destroys them.

Materials and Methods

Source of Materials

The types of sewage treatment studied included primary sedimentation in both Imhoff tanks and mechanically cleaned sedimentation tanks, secondary treatment by trickling filters and by activated sludge, final clarification with chlorination, and sludge digestion. Samples of effluent from Imhoff tanks were obtained from the Albany sewage treatment plant, with a design flow of 30 mgd and serving a population of 130,000; the Delmar plant, with a design flow of 1.6 mgd and serving 12,000 persons; and the Schenectady treatment plant, designed for 20 mgd and serving 100,000 people. Samples of sewage from mechanically cleaned primary sedimentation tanks were taken from the Colonie-Schenectady Road secondary treatment plant, designed for 0.4 mgd and serving 3,000 persons; and the Scotia primary treatment plant, with a design flow of 1.2 mgd and serving a population of 7,800. Samples of effluent from trickling filters and of final chlorinated effluents were obtained from the Rotterdam plant, with a design flow of 0.6 mgd and serving 5,000 persons, and from the Colonie-Schenectady Road plant. Im-

hoff tank sludge came from the Albany plant, digested sludge from Colonie, and aerated sludge samples from the Newark, New York, plant, with a design flow of 1.5 mgd and serving a population of 10,000. Raw sewage was sampled at the same time as the treated sewage.

Analytical Procedures

Samples consisted of pressings from cheesecloth swabs which were suspended in flowing sewage for 48 hr. The volume of swab expressions (approximately 100 ml) was reduced to 10 ml by adsorbing on 5 g of Dowex-1 resin, 200 to 400 mesh, 10-per cent cross linkage, to which bovine albumin had been added to give a concentration of 0.5 per cent, and eluting twice with 5-ml portions of beef extract broth. Antibiotics as follows: penicillin, 500 units; streptomycin, 2½ mg; and nystatin, 50 units per ml; were added along with 20-per cent by volume of diethyl ether and the eluates were stored in a dry ice chest.

Two criteria were indicative of virus destruction by sewage treatment: (a) the decreased frequency of virus isolations of treated sewage compared with that of raw sewage collected at the same time, and (b) a smaller number of infectious particles in the treated sewage.

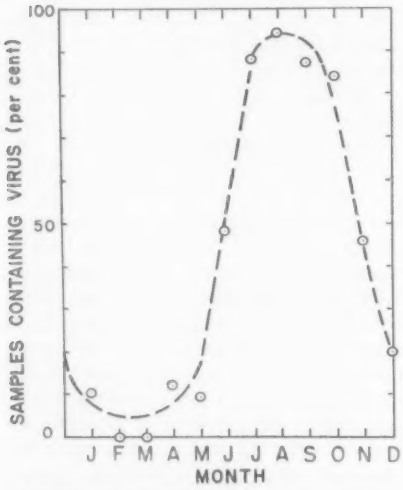

FIGURE 1.—Typical pattern of virus recovery from sewage for a consecutive 12-month period.

Frequency of isolation was measured as the per cent of samples from which viruses were isolated. Isolations were made in the following hosts: newborn mice (8), test tube cultures of explants of monkey kidney epithelium (9), and human amnion tissue (10), and of a continuous line of HeLa cells (11), and bottle cultures of monkey kidney epithelium tissue (12), over which agar was laid. Approximately 0.5 ml of swab concentrate was used for each method. Newborn mice were observed daily for two weeks for signs of disease; sick mice (paralyzed and spastic) were killed and their tissues saved for confirmatory passage and pathologic and serologic identification of virus. Tube and bottle tissue cultures were examined daily. Fluids from tube cultures in which the cells appeared abnormal were saved for passage and identification of strains. Plaques which formed in the bottle cultures were lifted from the surrounding agar and saved for passage and identification of isolates. Fluids were stored at −20°C or at −40°C (dry ice chest).

The number of infectious particles in sewage was measured by counting the plaques which formed in monkey kidney bottle cultures inoculated with 0.5 ml of swab concentrate during an observation period of from 7 to 10 days. Tissue cultures were kept at 33° to 35°C.

Results

Over a three-year period it was noted that the rate at which viruses were isolated from raw sewage depended on the season (7). In summer months approximately 80 per cent of raw sewage samples contained viruses (Figure 1), in June and November, about 50 per cent, and from January through May, less than 10 per cent. The sewage

TABLE I.—Viruses* Isolated from Raw and Treated Sewage in the Summer and Fall of 1957 from Treatment Plants at Seven Locations

Date	Albany		Colonie-Schenectady Road				Delmar		Scotia		Schenectady		Rotterdam			Newark	
	Raw	Effl.†	Raw	Prim. Effl.‡	Filter Effl.	Final Effl.§	Raw	Effl.†	Raw	Effl.‡	Raw	Effl.†	Raw	Filter Effl.	Final Effl.§	Raw	Aeration Tank Effl.
June																	
10–12	—	—	B_5	—	None	None	—	—	—	—	—	—	—	—	—	—	—
17–19	—	—	B_4,E_{13}	None	None	None	—	—	—	—	—	—	—	—	—	—	—
24–26	E_{13}	E_{13}	—	None	None	None	—	—	—	—	—	—	—	—	—	—	—
July																	
1–3	B	B	B	None	B_4	None	—	—	—	—	—	—	—	—	—	—	—
8–11	E_{12},A	E_{12},A_6	B_4,B_4,E_{12}	B_4,E_{12}	B_4,E_{13}	None	—	—	B	B_4	B_4	None	None	B_4	None	—	—
16–19	B_4,B_4	B_5	B_4,E	B	None	None	B_4	B_4,E_6	—	—	—	—	—	—	—	—	—
22–25	—	—	—	—	—	—	B_4,B_6	B_4	B_4,E_{10}	B_4	B_4,B_4	B_4	None	B_4	None	—	—
August																	
1–2	B_4,B_4,E_4,E_{12},A	B_4,E	B_4,B_4,E_{12},A	B_4,B_5	B_4,B_5	B_4,B_5	—	—	—	—	—	—	—	—	—	—	—
6–8	—	—	—	—	—	—	—	—	B_4	A	B_4A_4	B_4	B_4,B_4	None	B	—	—
12–14	B,E_6	B_4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19–22	—	—	B_4,B_5	—	None	B	—	—	—	—	—	—	—	—	—	—	—
26–28	B_4,E_4,P_2	B_4,E_{12},P_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
September																	
3–6	—	—	B_4	—	B_4,B_5,E_{11}	None	None	—	B_5	B,E_{11},A	B_4,E_7,E_{11},A	E_7,A_5	B_4,E_4,E_5,A_4	A	B_4	—	—
9–11	B,E_4,A_6,P_3	B,P_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16–18	—	—	A	—	A_4	E_{11},P_1	—	—	—	—	—	—	—	—	—	—	—
23–26	B_4,E_4,E_7,E_{12},A	P_2	—	—	—	—	—	—	—	—	—	—	—	—	—	B_4,P_1,A_{10}	None
October																	
1–2	—	—	P_1	—	E_{12},A_4	None	—	—	—	—	—	—	—	—	—	—	—
15–17	B_4,B_4,A_4	B,E_7,E_{11}	B_4,E_{12},P_1	—	E_{12},P_1	A_{10},P_1	—	—	—	—	—	—	—	—	—	A	None
23–25	B_5,P_2	P_2	A_7	—	E_{12}	None	—	—	—	—	—	—	—	—	—	—	—
November																	
4–12	P_2	None	A_5,A_6,E_{12}	—	None	E_{12}	—	—	—	—	—	—	—	—	—	—	—
12–15	A_4	E_{11},P_2	B	—	A	None	—	—	A	None	None	None	None	None	None	—	—
27–29	B_5,P_2	E_4,P_2	A_4,P_1	—	P_1	P_1	—	—	—	—	—	—	—	—	—	—	—
December																	
10–12	A_4	E_{11},P_2	None	—	—	None	—	—	—	—	—	—	—	—	—	—	—
16–18	B_4	E	None	—	None	None	—	—	—	—	—	—	—	—	—	—	—
24–26	E_4	None	None	—	None	None	—	—	—	—	—	—	—	—	—	—	—

* Key to virus designations as follows:

A—Coxsackie Group A; subscript number indicates type within Group A.

B—Coxsackie Group B; subscript number indicates type within Group B.

E—ECHO; subscript number indicates type within ECHO group.

P—polio; subscript number indicates type within polio group.

† Imhoff tank effluents.

‡ Primary sedimentation tank effluents.

§ Chlorinated final sedimentation tank effluents.

TABLE II.—Isolation of Viruses from Primary Treatment Effluents

Sewage Treatment Plant	Number of Samples Containing Viruses		
	Raw	Effluent	
		Imhoff Tank	Mechanically Cleaned Settling Tank
Albany	37	34	—
Delmar	6	7	—
Schenectady	8	9	—
Colonie-Schenectady Road	9	—	7
Scotia	9	—	7

samples for this study were collected from June through December 1957.

Raw Waste

Table I lists the types of treatment, dates, and kinds of viruses isolated during the 1957 sampling period. In this experience, 90 per cent of the total raw sewage samples collected contained virus. There were no major differences in the frequency of total isolations from raw sewage from one plant to another, although the types of viruses differed. The types of viruses encountered changed as the sampling period progressed. Coxsackie Group B viruses and ECHO virus, type 12, were the most common isolates through June and July. In August and September, polioviruses, Coxsackie Group A viruses, and other types of ECHO viruses were isolated also. From October on, the Coxsackie viruses, Group B, were found only as often as were other kinds of viruses.

Primary Treatment

Primary sedimentation did not lessen the frequency with which viruses were isolated (Table II). The kinds of viruses found following primary treatment were usually similar to those in the raw sewage. Plaque counts of settled sewage effluent, however, indicated that a reduction in the total number of infectious particles occurred (Table III), probably from removal of virus in the settleable solids. Viruses were isolated also from the Hudson River, at distances as great as 400 ft from the outfall of the Albany sewage treatment plant.

The total number of influent and effluent samples from each treatment plant was equal. Therefore the number of isolations can be compared directly to show that no decrease by treatment occurred (Tables II, III, and IV).

Secondary Treatment and Chlorination

Treatment on trickling filters did not remove viruses completely, since samples of sewage which had passed through the filters contained viruses as often as did raw sewage. Plaque counts, however, were reduced by 40 per cent (Table III), indicating that the processes involved have some destructive effect and do reduce the density. Viruses were not found in the one sample taken of scrapings from the growths on filter stones.

Effluents from secondary treatment plants that had been chlorinated for disinfection contained viruses about a third of the time. Residual chlorine values reported for these samples were near the recommended value of 0.5 ppm (Table IV). The chlorination practiced, however, had some destructive action on viruses, as plaque counts of

TABLE III.—Isolation of Viruses as Plaque-Forming Units (PFU)

Plant	Plaque-Forming Units 1957 (Aggregate)			
	Raw	Effluent		
		Primary Treatment	Trickling Filter	Final Plant
Albany	25	22	—	—
Schenectady	7	1	—	—
Colonie-Schenectady Road	38	—	22	7
Rotterdam	8	—	0	0
Scotia	5	1	—	—

TABLE IV.—Virus Isolations from Secondary Treatment Plant Effluents

Plant	Date	Virus*	Plaque-Forming Units		Reported Residual Chlorine (ppm)
			Influent	Effluent	
A	July 31–Aug. 2	B_4,B_5	20	2	0.5
↓	Aug. 19–22	B	3	0	0.40–0.75
↓	Sept. 16–18	E_{11}	0	2	0.30–0.75
↓	Oct. 15–17	P_1,A	2	3	None reported
↓	Nov. 4–12	E_{12}	—	—	0.15–0.35
↓	Nov. 27–29	+	0	0	—
B	Aug. 6–8	B	0	0	0.3–0.75
↓	Sept. 4–6	B_4	8	0	0.0–0.75

* Key to virus designations as follows:
A—Coxsackie Group A.
B—Coxsackie Group B; subscript number indicates type within Group B.
E—ECHO; subscript number indicates type within ECHO group.
P—polio; subscript number indicates type within polio group.

chlorinated effluents were lowered. Raw sewage which had been chlorinated to reduce nuisance in plants, involving concentrations of 0.1 to 0.3 ppm residual chlorine, contained viruses as often as nonchlorinated raw sewage.

Sludge

A few samples of aeration tank effluent were found to be free of viruses (Table V). The return sludge collected in a series from which the data are not included in Table V contained virus on one occasion, suggesting that while viruses were removed by the process, they were not necessarily destroyed. In a laboratory demonstration at least 99 per cent of virus added to activated sludge was removed and not recovered in the sludge.

Two samples of Imhoff tank sludge and two of sludge digested thirty days did not contain viruses. Others have tried to isolate polioviruses from digested sludge and failed, although they have been found in raw sludge (5).

Discussion

It is clear that several of the present methods of sewage treatment do not destroy the enteroviruses. In primary treatment the failure to disinfect sewage may be alleviated by dilution and biological oxidation in the receiving stream. In this report it was shown that viruses were found at least 400 ft below the outfall of a primary treatment plant. Bacterial pathogens, tubercle bacilli for example, are also known to survive primary treatment (13).

Secondary treatment by trickling filters without chlorination is shown to be inadequate for virus destruction. Acid-fast bacilli also survived such treatment (13). Laboratory studies, on the other hand, indicated a reduction in *Salmonellae* of up to 99.9 per cent (14). If secondary treatment includes chlorination, it may destroy viruses. Laboratory studies of the effect

TABLE V.—Isolation of Viruses from Activated Sludge Plant

Sample	Virus*	Isolations	
		Plaque Counts	Infected Mice (per cent)
Raw	B_5,A,P_1	2	58
Primary effluent	B_5,A,P_1	5	57
Aerator effluent	None	0	0
Final effluent	None	0	0
Tank sludge return	None	0	0

* Key to virus designations as follows:
A—Coxsackie Group A.
B_5—Coxsackie Group B, type 5.
P_1—polio type 1.

of combined residual chlorine on viruses indicate that, depending on hydrogen ion concentration and temperature, residual chlorine values of 9.0 ppm or greater with 15 min contact, or contact periods of 4 hr with combined chlorine values of 0.5 ppm, are necessary for inactivation (15). Plant studies of the survival of bacterial pathogens following chlorination have been summarized recently (13) and indicate that ordinary chlorination does not destroy tubercle bacilli. *Salmonellae* have also been isolated from sewage following secondary treatment (7).

Recent work (6) showed survival of viruses in 4 of 41 sewage samples following treatment by activated sludge. Bacterial pathogens, *Salmonellae*, from activated sludge, and acid-fast bacteria from settled and digested sludge were reported (16).

The potential reservoir of virus disease is great in raw sewage, poor water supplies, and inadequately treated sewage. The standard for disinfection of sewage should be raised, if its intent is destruction of viral as well as bacterial pathogens.

Continuous evaluation of the standards for disinfection of sewage may be necessary. Many kinds of viruses have now been isolated from sewage. Each strain has its individual characteristics of resistance, virulence, and stability. An adequate standard for disinfection should take into account the expected range of variation in these properties.

Summary

From 140 samples of raw and treated sewage collected in the summer and fall of 1957, over 166 strains of viruses were isolated. A study of the frequency of isolation and concentration of infectious particles in the samples indicates that existing types of sewage treatment may not destroy viruses.

Primary treatment and secondary treatment by trickling filters did not reduce the frequency of virus isolations and reduced the concentration of infectious particles only slightly. Chlorination for disinfection, often but not always, reduced the frequency of isolation and the concentration of particles. Viruses were found in a receiving stream 400 ft below the outfall of a primary treatment plant. Effluent from an activated sludge treatment plant did not contain viruses, nor were they found in Imhoff tank or digested sludge.

Acknowledgments

Pathologic identifications of Coxsackie virus infections were made by Dr. Joseph Schleifstein.

The technical help of Mr. Thomas McLaughlin is greatly appreciated.

Sera for identification of agents were generously given by Miss Grace Sickles and Dr. Johan Winsser.

References

1. "Chlorination of Sewage and Industrial Wastes." Manual of Practice No. 4, Federation of Sewage and Industrial Wastes Associations, Washington 16, D.C., p. 18 (1951).
2. Chang, S. L., and Fair, G. M., "Viability and Destruction of the Cysts of *Endameba histolytica*." *Jour. Amer. Water Works Assn.*, **33**, 10, 1705 (Oct. 1941).
3. d'Herelle, F., "The Bacteriophage: Its Role in Immunity." p. 19, Williams and Wilkins, Baltimore, Md. (1922).
4. State Medical Institute of Sweden, "Investigations on Epidemic Infantile Paralysis. Report to the XV International Congress on Hygiene and Demography, Washington, 1912." Uppsala, Sweden (1912).
5. Gear, J. H. S., "The Virus of Poliomyelitis: Its Distribution and Methods of Spread." *Jour. Roy. San. Inst.* (Brit.), **69**, 3, 149 (1949).
6. Mack, W. N., Mallman, W. L., Bloom, H. H., and Krueger, B. J., "Isolation of Enteric Viruses and *Salmonellae* from Sewage. I. Comparison of Coliform and Enterococci Incidence to the Isolation of Viruses." THIS JOURNAL, **30**, 8, 957 (Aug. 1958).
7. Kelly, S. M., Clark, M. E., and Coleman, M. B., "Demonstration of Infectious

Agents in Sewage." *Amer. Jour. Pub. Health*, **45**, 11, 1438 (1955).

8. Dalldorf, G., and Sickles, G. M., "An Unidentified, Filtrable Agent Isolated from the Feces of Children with Paralysis." *Science*, **108**, 2794, 61 (1948).
9. Robbins, F. C., Weller, T. H., and Enders, J. R., "Studies on the Cultivation of Poliomyelitis Viruses in Tissue Culture. II. The Propagation of the Poliomyelitis Viruses in Roller-Tube Cultures of Various Human Tissues." *Jour. Immunol.*, **69**, 6, 673 (1952).
10. Zitcer, E. M., Fogh, J., and Dunnebacke, T. H., "Human Amnion Cells for Large-Scale Production of Polio Virus." *Science*, **122**, 3157, 30 (1955).
11. Scherer, W. F., Syverton, J. T., and Gey, G. O., "Studies on the Propagation in vitro of Poliomyelitis Viruses. IV. Viral Multiplication in a Stable Strain of Human Malignant Epithelial Cells (Strain HeLa) Derived from an Epidermoid Carcinoma of the Cervix." *Jour. Exptl. Med.*, **97**, 5, 695 (1953).
12. Hsiung, G. D., and Melnick, J. L., "Plaque Formation with Poliomyelitis, Coxsackie, and Orphan (Echo) Viruses in Bottle Cultures of Monkey Epithelial Cells." *Virology*, **1**, 5, 533 (1955).
13. Greenberg, A. E., and Kupka, E., "Tuberculosis Transmission by Waste Waters —A Review." THIS JOURNAL, **29**, 5, 524 (May 1957).
14. Green, C. E., and Beard, P. J., "Survival of E. typhi in Sewage Treatment Plant Processes." *Amer. Jour. Pub. Health*, **28**, 6, 762 (1938).
15. Kelly, S., and Sanderson, W. W., Unpublished data.
16. Pramer, D., Heukelekian, H., and Ragotzkie, R. A., "Survival of Tubercle Bacilli in Various Sewage Treatment Processes. I. Development of a Method for the Quantitative Recovery of Mycobacteria from Sewage." *Pub. Health Repts.*, **65**, 27, 851 (1950).

MILL CREEK PLANT DEDICATION

On June 18 the Metropolitan Sewage Disposal System, composed of the City of Cincinnati and 26 participating political subdivisions, will dedicate the Mill Creek Sewage Works. The Mill Creek plant is a $26 million project and is a part of the $59 million program for pollution abatement, according to A. D. Caster, Principal Sewage Disposal Engineer of Cincinnati.

Among the highlights of the 2:15 PM program will be the welcoming address by Cincinnati Mayor Donald Clancy followed by guided tours and films of the plant facilities.

Preceding the ceremonies, the Cincinnati Chamber of Commerce will hold a luncheon at 12:15 PM at the Netherland Hilton Hotel.

The Ohio Sewage and Industrial Wastes Treatment Conference will participate in the dedication while meeting at the same hotel June 17–19.

BACTERIAL DEGRADATION OF ABS

II. COMPLETE-MIXING ACTIVATED SLUDGE *

By Ross E. McKinney and Eugene J. Donovan †

Associate Professor, and Research Assistant, Massachusetts Institute of Technology, Cambridge, Mass.

The failure of activated sludge to completely degrade commercial alkyl benzene sulfonates (ABS) has led to some problems in sewage effluents. Previous laboratory studies (1) (2) have shown that the basic problem lies in the structure of ABS. The presence of a quaternary carbon in the hydrocarbon side chain is believed to be the cause of incomplete metabolism. In view of the fact that ABS cannot be completely degraded, it is important to obtain the maximum degree of biological metabolism in order that the free ABS remaining in the effluent is minimum.

At the present time the active ABS content in domestic sewage varies from 1 to 10 mg/l. It appears that the active ABS content in sewage reaching the aeration tank will not rise much above 10 mg/l, except in unusual cases, for the next few years. In view of this prediction a study was started to determine to what extent ABS could be metabolized by activated sludge when added at 10 mg/l concentration along with other organic nutrients.

Conventional Activated Sludge

In order to determine to what extent ABS was metabolized by conventional activated sludge, five laboratory activated sludge units were set up for tests. Each of these units was 1.5 liters in capacity and was operated on a 24-hr fill-and-draw cycle. The mixed liquor was settled for one hour after which one liter of supernatant liquor was poured off and replaced with one liter of synthetic sewage. The units were aerated for 23 hr and the procedure repeated.

The synthetic sewage consisted of 300 mg/l glucose, 300 mg/l nutrient broth, 300 mg/l sodium benzoate, and 300 mg/l dibasic potassium phosphate. The units were started from 500 ml Boston, Massachusetts, sewage. After one week's operation without any sludge wasting, a regular sludge wasting program was started. In one unit 600 ml of mixed liquor was wasted daily. The other units had 400, 200, 100, and 25 ml mixed liquor wasted daily. The units were then allowed to operate for two additional weeks to bring about equilibrium of mixed liquor suspended solids. Only the 25-ml sludge waste system was not in equilibrium at this time. Daily feedings of 10 mg/l ABS were started in all units.

Daily analyses were made of mixed liquor suspended solids to determine the quantity of solids wasted daily. Spectrophotometric analyses of ABS by the 1-methyl heptylamine method of Fairing and Short (3) were made at irregular intervals over a 46-day period. The average daily ABS balances in the various units are shown in Table I. The daily balances are in total quantity figures, milligrams, rather than in concentration figures, milligrams per liter.

The total weight of mixed liquor

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6-9, 1958.

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TABLE I.—Average Daily ABS Balance in Activated Sludge Units with Varying Solids Wasted

Waste Mixed Liquor (ml)	Total SS (mg)	Total Soluble ABS (mg)	Total Adsorbed ABS (mg)	Total Unoxidized ABS (mg)	ABS Wasted (mg)			Remaining Unoxidized ABS (mg)	ABS Metabolized (mg)	Sludge Produced (mg)	ABS Metabolized per Unit Sludge Produced (mg/mg)
					Effluent	Sludge	Total				
25	6,900	6.7	4.5	11.2	4.5	0.1	4.6	6.6	5.4	115	0.047
100	2,820	4.5	1.7	6.2	3.0	0.1	3.1	3.1	6.9	188	0.036
200	2,220	3.9	1.2	5.1	2.6	0.2	2.8	2.3	7.2	295	0.024
400	1,380	3.6	0.9	4.5	2.4	0.2	2.6	1.9	7.4	368	0.020
600	970	3.3	0.7	4.0	2.2	0.2	2.4	1.6	7.6	387	0.020

suspended solids was determined by the membrane filter method (4). The 25-ml waste showed a definite increase in mixed liquor suspended solids throughout most of this study while the other units maintained relatively constant suspended solids in the aeration tanks. The total soluble ABS was determined from the membrane filtrate from the suspended solids determination. The adsorbed ABS was determined from the curve shown in Figure 1, which was obtained from a study of the adsorption of ABS on this synthetic sewage activated sludge. The sum of the soluble ABS and the adsorbed ABS gave the total unoxidized ABS in the system.

The effluent from each unit consisted of the solids wasted and settled supernatant liquor and totalled 1.0 liter. The quantities of ABS in mg in these two phases are shown in the columns labeled "Effluent" and "Sludge." It can be seen that very little ABS was lost with the solids but that most of the ABS was in the effluent. It is indicated that the operation of the systems definitely affected the ABS in solution. With a low wasting of solids there were 4.5 mg ABS in solution while with the maximum wasting of solids there were only 2.2 mg of ABS in solution. As shown in Table I, subtraction of the "ABS Wasted" from the "Total Unoxidized ABS" yielded the "Remaining Unoxidized ABS." Since the systems were in equilibrium with regard to ABS reduction the difference between the 10 mg ABS in the feed and the ABS wasted yielded the ABS metabolized.

The percentage ABS oxidation ranged from 54 to 76 per cent. Since the ABS

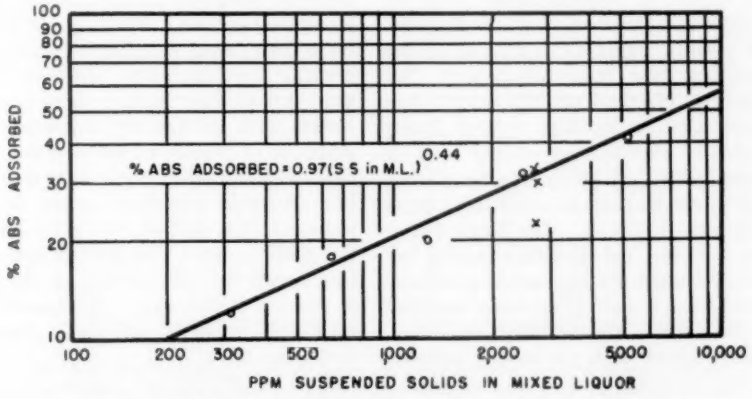

FIGURE 1.—Adsorption of ABS by synthetic sewage activated sludge.

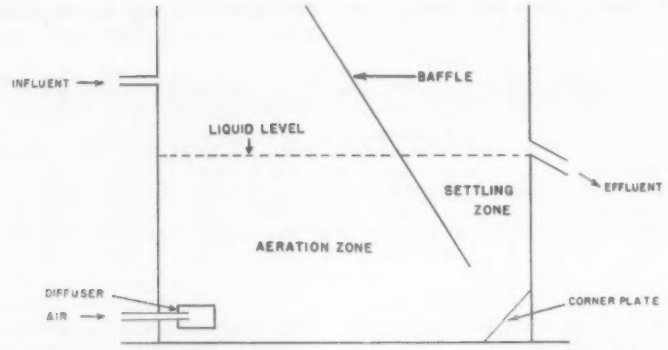

FIGURE 2.—Schematic diagram of laboratory model of activated sludge unit used in test work.

determination measures primarily undegraded material, this means that the ABS wasted represents unmetabolized ABS in its original form. It has been found that if the side chain is oxidized even slightly, the ABS test does not pick it up. Thus, the results do not indicate whether the ABS metabolized was completely metabolized or just partially metabolized.

The removal of ABS was a function of sludge activity although a small amount of the ABS was lost by adsorption to the activated sludge. The rapid rate of growth appeared to stimulate the microbial activity.

Complete Mixing

Although it appeared that ABS removal was a function of sludge activity, the complete mixing activated sludge plant at Dale Brook Bleachery (5), formerly Ho-Ho-Kus Bleachery, had shown that with high mixed liquor suspended solids and a low organic concentration, frothing due to syndets used in the bleaching and dyeing processes was very low. The basic difference between the complete-mixing activated sludge system and the conventional activated sludge process was that in the former the influent was thoroughly mixed with the entire contents of the aeration tank. The complete-mixing process permitted maintenance of the lowest possible organic concentration in the aeration tank. In the conventional activated sludge system the organic concentration is a maximum immediately after the introduction of organic matter and a minimum at the end of the aeration period. This variation in organic concentration results in a feed-starve cycle which prevents development of the optimum biological population. The complete-mixing unit is designed to permit a constant organic concentration at all times to allow development of the optimum biological population.

The laboratory equipment was composed of 1.5-liter units which were divided into two sections, a 1.25-liter aeration section, and a 0.25-liter sedimentation section. The organic wastes were introduced continuously into the aeration section where diffused aeration completely mixed the organic wastes with the aerator contents. The addition of wastes to the aeration section caused displacement of mixed liquor from the aeration section to the sedimentation section where the sludge floc settled out. The settled supernatant liquor was displaced from the unit at the top of the tank. The laboratory unit is shown in the schematic drawing in Figure 2.

Two units were set up, one on synthetic sewage and one on domestic sew-

age from Boston. The synthetic sewage strength was reduced to equal that of the city sewage to show that the nature of the organics has no effect on the metabolic reactions. Settled Boston sewage averaged approximately 125 mg/l 5-day BOD. The synthetic sewage had the following formulation:

200 mg/l nutrient broth
500 mg/l sodium bicarbonate
50 mg/l potassium phosphate, dibasic
10 mg/l ammonium sulfate

The average 5-day BOD of the synthetic sewage was 127 mg/l.

The complete-mixing units were initially started by building up a small quantity of activated sludge on a batch feed basis for two days. The synthetic sewage unit was given a small quantity of activated sludge to permit good flocculation since its substrate was completely soluble. The domestic sewage unit flocculated easily from the beginning due to the agitation of the colloids. When the continuous feed operations were started, the mixed liquor suspended solids concentrations were 580 mg/l for the synthetic sewage unit and 50 mg/l for the domestic sewage unit. Both units were fed at the rate of 4.0 l/day. This gave a total retention period of 9 hr in the entire unit or 7.5-hr aeration and 1.5-hr sedimentation.

Operation

The laboratory units were operated for 34 days without any additional ABS being added to the substrates. On the 35th day, 2 mg/l ABS were placed in the feeds. The ABS concentration was increased to 4 mg/l on the 47th day, to 6 mg/l on the 58th day, to 8 mg/l on the 72nd day, and to 10 mg/l on the 83rd day. The initial run was terminated on the 106th day of operation.

Synthetic Sewage

The synthetic sewage unit showed a mixed liquor suspended solids concentration between 1,000 and 2,000 mg/l. The variation in suspended solids is

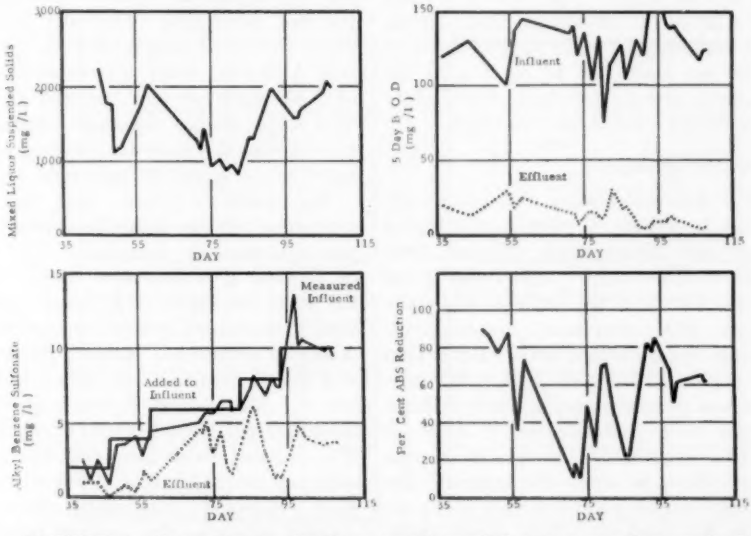

FIGURE 3.—Operating results from complete mixing system using synthetic sewage and receiving varying concentrations of ABS with total retention of nine hours.

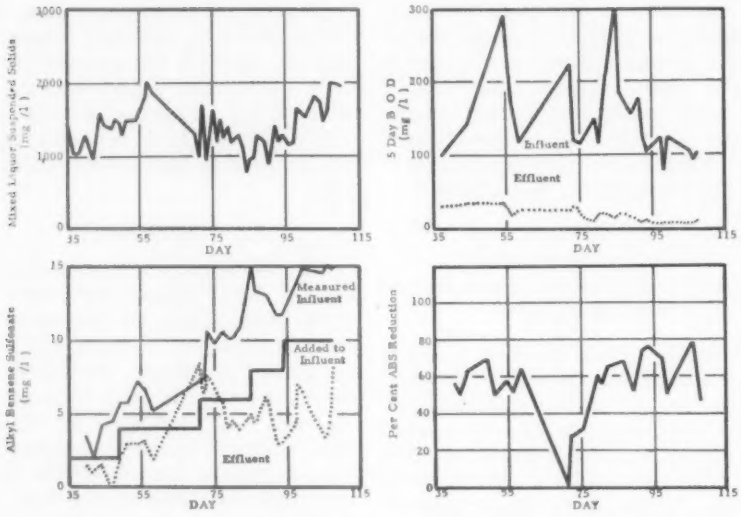

FIGURE 4.—Operating results from complete mixing system using domestic sewage and receiving varying concentrations of ABS with total retention of nine hours.

shown in Figure 3. The 5-day BOD of the influent and the effluent showed that this unit was operating satisfactorily. The ABS added to the influent, the actual measured influent ABS, and the ABS in the effluent are also plotted. The reduction of ABS ranged from 15 to 80 per cent. At 10 mg/l ABS the synthetic sewage unit indicated slightly over 60 per cent ABS reduction.

Domestic Sewage

The domestic sewage unit results are shown in Figure 4. The mixed liquor suspended solids again ranged from 1,000 to 2,000 mg/l. The 5-day BOD varied widely in the influent while the effluent BOD was relatively constant. The sewage contained some ABS so that the measured influent ABS concentration was greater than in the synthetic sewage unit. The degree of ABS reduction remained at a relatively constant 60 per cent throughout the 106-day period except for an upset between the 55th and 75th days, corresponding with a vacation period. When closer attention to operation was resumed after this period, the unit quickly recovered from the upset.

The data on the synthetic sewage and the domestic sewage showed that there was no significant difference between the two substrates. The tests in both units indicated approximately 60 per cent ABS reduction. The total amount of ABS removed per day was 24 mg. The only sludge wasting which occurred was the periodic removal of 25 ml of mixed liquor for analyses.

The synthetic sewage unit was discontinued but the domestic sewage unit was continued in operation. The rate of feeding was increased from 4.0 to 6.0 liters per day to build up the mixed liquor suspended solids concentration. Analyses were made between the 147th and 183rd days and are shown in Figure 5. The mixed liquor suspended solids ranged from 3,000 to 6,000 mg/l. The influent BOD averaged 110 mg/l between the 150th and 170th day and then jumped to 150 mg/l. The suspended solids in the aerator followed the rising pattern of BOD loading as did the rate of ABS removal. When

the suspended solids in the aerator were about 3,000 mg/l the rate of ABS reduction was a little over 60 per cent but increased to 80 per cent when the suspended solids rose to 6,000 mg/l.

Discussion

The failure of microorganisms to completely degrade commercial ABS poses a problem with the undergraded fraction. When agitated violently, the undergraded ABS froths, which is its major effect on activated sludge systems. Even though ABS is not amenable to complete biological degradation, it is important to obtain the maximum possible degree of ABS degradation in order to minimize frothing. With conventional activated sludge, the degree of ABS removal appears to be related to the rate of synthesis of sludge, and as a result to the quantity of sludge wasted. This would indicate that the high-rate or modified activated sludge systems would yield the best ABS removals.

The complete-mixing activated sludge system depends on endogenous metabolism for organic waste stabilization. The rate of sludge synthesis is very low but the ABS reduction is relatively high. The fact that a high degree of sludge synthesis in conventional activated sludge and a low degree of sludge synthesis in complete mixing activated sludge both yield good ABS reductions seems contradictory but there is an explanation for these differences. Both systems are designed to keep the bacterial population at its maximum activity. With a high-rate activated sludge system the bacterial activity is stimulated by a high food to microorganism ratio and results in a rapid synthesis of new cells. In the complete mixing system the bacterial activity is maintained at a constant level by the low food to microorganism ratio. The large number of microorganisms carry on very little metabolism by themselves but together are responsible for an excellent reduction of organic matter. Thus, in one system, removal of ABS is accomplished by a small number of microorganisms growing rapidly and in the other system by a large number of microorganisms on the verge of starvation.

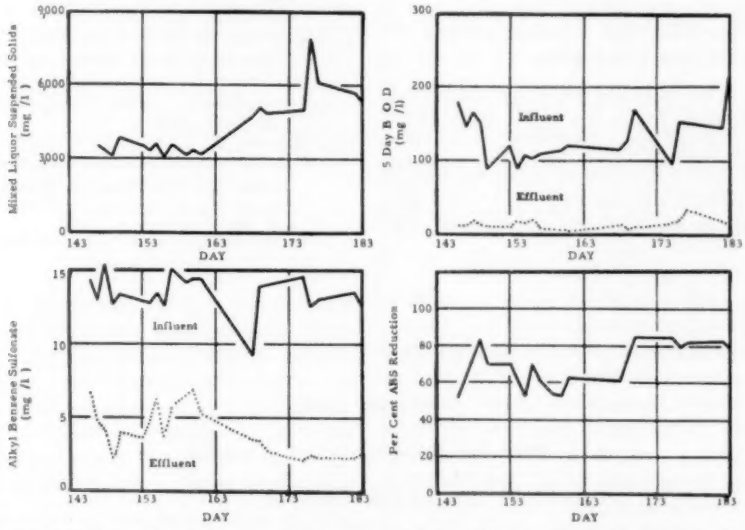

FIGURE 5.—Operating results from complete-mixing system using domestic sewage and receiving 10 mg/l ABS daily with total retention of six hours.

While a high-rate wasting system is able to reduce the ABS concentration to a minimum, the remaining ABS concentration may still be sufficient to cause frothing. In many activated sludge systems, reduction of solids has resulted in extreme frothing. On the other hand, the high-rate activated sludge systems which accomplish only 60 to 70 per cent BOD reduction may not have a frothing problem if the ABS remains tied up with the complex, undergraded BOD. Unfortunately, it is not possible to predict at this time the exact effect of high-rate wasting of excess sludge on the ABS problem since each sewage and each treatment plant has its own special characteristics. Each plant will have to be evaluated on its own merits.

In order to determine if the complete-mixing activated sludge system has definite potentialities in the control of froth in activated sludge systems, a full-scale study is planned on the conversion of an existing activated sludge system having a frothing problem to a complete-mixing system.

Conclusions

The following conclusions can be drawn from this study:

1. Conventional activated sludge systems should give up to 75 per cent reduction in commercial ABS.
2. The reduction of ABS appears to be related to the rate of sludge synthesis in conventional activated sludge.
3. Complete-mixing activated sludge systems should give up to 80 per cent ABS reduction.
4. The reduction of ABS appears to be a function of the sludge mass in complete-mixing activated sludge.
5. The methylene blue test for ABS does not give a quantitative measure of partially metabolized ABS and can be used only to determine the unmetabolized portion of ABS.

Acknowledgment

The authors would like to acknowledge the financial support of the Association of American Soap and Glycerine Producers which made this study possible.

References

1. McKinney, R. E., and Symons, J. M., "Bacterial Degradation of ABS. I. Fundamental Biochemistry." THIS JOURNAL, **31**, 5, 549 (May 1959).
2. Sawyer, C. N., and Ryckman, D. W., "Anionic Synthetic Detergents and Water Supply Problems." *Jour. Amer. Water Works Assn.*, **49**, 4, 480 (Apr. 1957).
3. Fairing, J. D., and Short, F. R., "Spectrophotometric Determination of Alkyl Benzene Sulfonate Detergents in Surface Water and Sewage." *Anal. Chem.*, **28**, 1827 (1956).
4. Engelbrecht, R. S., and McKinney, R. E., "Membrane Filter Method Applied to Activated Sludge Suspended Solids Determinations." THIS JOURNAL, **28**, 11, 1321 (Nov. 1956).
5. McKinney, R. E., Symons, J. M., Shifrin, W. G., and Vezina, M., "Design and Operation of a Complete Mixing Activated Sludge System." THIS JOURNAL, **30**, 3, 287 (Mar. 1958).

October 12–15

Plan for the Federation Meeting

DALLAS, TEXAS

Industrial Wastes

DEVELOPMENT OF THE ANAEROBIC CONTACT PROCESS *

II. ANCILLARY INVESTIGATIONS AND SPECIAL EXPERIMENTS

By George J. Schroepfer and Norman R. Ziemke

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This is the second of a two-part paper summarizing the results of three years of research on the application of the anaerobic contact process in the treatment of various types of industrial wastes and municipal sewage. Part I included data from pilot-plant investigations and an economic analysis and was published in This Journal, **31**, 2, 164 (Feb. 1959). Part II reports on ancillary investigations and special experiments, summarizes the study, and offers the conclusions.

This investigation was supported by Research Grant No. 4419, from the National Institutes of Health of the Public Health Service.

Special Investigations and Experiments

During the research program a number of experiments were carried out on active sludges taken from the pilot plants. These investigations were for the most part planned to study the basic actions involved in the contact and separation portions of the anaerobic contact process and to evaluate the physical, chemical, and biological characteristics of anaerobic sludge.

Adsorption and Stabilization Characteristics

The complexity of the interrelated physical, chemical, and biological reactions occurring when a typical heterogeneous mixture of organic matter in wastewater is acted on by a mixed culture of anaerobic sludge, makes the resolution into a few basic actions appear quite difficult. Although the metabolic processes of the individual organisms are complex, the end products of the anaerobic fermentation process are quite constant. The products of the completed reaction are for the most part carbon dioxide, methane, and in some cases hydrogen, plus an inert humus-like material. In wastewater treatment it is the degree of stabilization which is of importance and not the way the result was achieved.

Basic Actions

When a waste containing both suspended and dissolved organic materials is mixed with an active anaerobic sludge culture, there is initiated a chain of physical and biochemical reactions which remove and progressively stabilize the organic matter contained in the waste stream. It is this over-all chain of reactions which results in a reduction in the organic content of the waste. Experimentally on a batch basis this

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

chain of reactions was found to take place in two distinct stages which, however, may take place concurrently. The process can be divided into two general reactions: (a) adsorption or transfer of organic matter from the waste to the separable solid sludge particles, and (b) the subsequent stabilization of this organic material into products. Experimentally the rate of transfer of organic matter onto particles of anaerobic sludge has been found to be quite rapid when compared to the rate of stabilization.

Mechanism

There appears to be some disagreement in the literature with regard to the actual mechanism of the transfer of organic matter from a waste substrate to biological floc particles and its subsequent stabilization. However, there seems to be agreement that enzymes are intimately involved. The kinetics of enzyme reactions can often be interpreted by an activated complex theory such as that proposed by Michaelis and Menten (1). Considering the extreme heterogeneity of the reactions, it is quite certain that the average over-all kinetics can be established only on an approximate basis. The following discussion presents a hypothesis on the kinetics of the reactions occurring in the anaerobic process of stabilization based on the Michaelis-Menten theory.

The basic hypothesis of the theory on the kinetics of enzyme reactions can be stated as follows:

$$C + E \underset{k_2}{\overset{k_1}{\rightleftarrows}} CE^* \quad \ldots\ldots (1)$$

and

$$CE^* \xrightarrow{k_3} P + E \quad \ldots\ldots (2)$$

where

C = concentration of substrate,
E = concentration of enzyme,
CE^* = intermediate activated enzyme organic complex,
k_1 and k_2 = forward and backward rate constants,
P = concentration of products formed, and
k_3 = reaction rate constant.

These reactions can be likened to the two-stage adsorption and stabilization of organic matter by anaerobic sludge. The so-called adsorption reaction can be compared to the formation of an activated enzyme complex as in Equation 1 and the stabilization reaction by Equation 2. Considering only the first step of the reaction, the rate of disappearance of organic molecules as the reaction proceeds toward equilibrium can be stated:

$$-\frac{dC}{dt} = k_1CE - k_2CE^* \quad \ldots\ldots (3)$$

It was shown in experiments which will be described later that the activated complex in the case of anaerobic sludge is apparently quite stable and the backward rate of reaction is negligible. Thus if E is defined as the number of enzyme sites still to be occupied at any instant, *i.e.*, the number of sites remaining to be occupied before equilibrium is reached, then the reaction will proceed toward equilibrium at a rate which is dependent only on the concentration of organic molecules (C) and the concentration of available sites (E). On this basis the rate of disappearance of organic molecules as the reaction is tending toward equilibrium can be simplified as follows:

$$-\frac{dC}{dt} = CE \quad \ldots\ldots (4)$$

However, if the disappearance of one organic molecule from the substrate results in the removal of one available enzyme site, the following relationships can be stated:

$$E_o = C_o - C_e \quad \ldots\ldots (5a)$$

$$E_t = C_o - C \quad \ldots\ldots (5b)$$

$$E = E_o - E_t \quad \ldots\ldots (5c)$$

$$E = C - C_e \quad \ldots\ldots (5d)$$

where

E_o = enzyme sites remaining to be occupied at time zero,
E_t = enzyme sites which have been occupied to time t,
E = enzyme sites remaining to be occupied at any time t,
C_o = concentration of organic molecules at time zero,
C_e = concentration of organic molecules at equilibrium, and
C = concentration of organic molecules at any time t.

Substituting in Equation 4:

$$-\frac{dC}{dt} = k_1C(C-C_e) = k_1C^2 - k_1C_eC \quad \ldots (6)$$

Integrating, evaluating the constant of integration, and simplifying:

$$t = \frac{1}{k_1C_e} \ln \frac{C_o}{C_o - C_e} \cdot \frac{C - C_e}{C} \quad \ldots (7)$$

This has the form of a second order rate reaction and has been developed to describe the adsorption rate as the reaction proceeds toward equilibrium.

The second stage or stabilization portion of the reaction is described by Equation 2. This reaction undoubtedly proceeds along with the adsorption reaction as it proceeds toward equilibrium. However, an analysis of the stabilization reaction can be made assuming that the initial adsorption reaction has achieved equilibrium. At this point it is assumed that the concentration of the activated complex (CE^*) remains fairly constant. The logical basis of this assumption is that the concentration of the catalytic enzyme in the system at least for short periods of time remains constant since it is not used up by the reaction. Also, the rate of adsorption is quite rapid and as an enzyme site is released by the stabilization reaction it is occupied by another organic molecule quite rapidly in order to maintain the equilibrium adsorption conditions. On this basis the rate of disappearance of organic molecules by stabilization can be described:

$$-\frac{dC}{dt} = k_3CE^* \quad \ldots (8)$$

but at adsorption equilibrium, CE^* = constant = K; therefore:

$$-\frac{dC}{dt} = k_3K = \frac{1}{K_2} \quad \ldots (9)$$

Integrating and evaluating the constant of integration:

$$t = K_2(C_e - C) \quad \ldots (10)$$

where $K_2 = k_3CE^*$ or $k_3 = \frac{K_2}{CE^*}$.

This has the form of a zero order rate reaction and indicates a linear relationship for the rate of stabilization after adsorption equilibrium has been reached.

It should be re-emphasized at this point that the development of the reaction kinetics for the adsorption and stabilization reactions as described above are based on a number of simplifying assumptions. The validity of these assumptions and the accuracy with which the hypothesis describes the actual reaction kinetics involved in the anaerobic process can only be checked by controlled experiments. This was the objective of a series of batch tests which are described below.

Experiments

A series of experiments were run on a batch basis to determine the adsorption and stabilization characteristics of anaerobic sludge. Synthetic milk waste and domestic sewage were used as the adsorbate and various anaerobic cultures taken from the pilot plants were used as the adsorbent. The waste and the sludge were mixed continuously at constant temperature and samples were taken at measured intervals of time, centrifuged to remove solids, and the COD determined on the clear supernatant. The main objective of these somewhat preliminary experi-

TABLE I.—Summary Data for Adsorption and Stabilization Tests Using Synthetic Milk as Adsorbate

Test No.	Adsorbate	Adsorbent		Mixture				
	COD* (ppm)	Type Sludge	SS (ppm)	Temp. of Mix (°C)	C_o (ppm COD)	C_e (% remaining)	k_1	k_2
1	1,000	A†	5,076	25	602	45	−0.333	−0.228
2	1,000	A†	4,046	25	567	45	−1.940	−0.454
3	1,000	A†	5,290	25	680	55	−0.625	−0.741
4	1,000	A†	3,964	25	691	63	−1.27	−0.193
5	1,000	C‡	8,616	26	612	49	−2.04	−0.179
6	1,000	A†	6,832	35	641	57	−0.518	−0.388
7	2,000	B§	12,120	35	1,160	55	−0.713	−0.444
8	1,000	B§	12,120	35	607	57	−0.430	−0.465
9	1,000	C‡	8,172	23	609	51	−1.390	−0.292
10	500	C‡	8,172	25	335	49	−0.709	−0.218
11	2,000	C‡	5,156	23	1,202	75	−0.553	−0.333
12	1,000	C‡	5,156	23	629	70	−0.400	−0.333
13	1,000	A†	5,940	35	786	57	−0.304	−0.332

* Approximate.
† Sludge from pilot plant I.
‡ Sludge from Accelator model.
§ Sludge from pilot plant II.

ments was to determine if the Michaelis-Menten hypothesis on the kinetics of enzyme reactions could be applied to two-stage adsorption and stabilization of organic matter by anaerobic sludge. In this respect if Equation 7 remains true for the adsorption reaction as it approaches equilibrium, a plot of time against the logarithm of the factor

$$\frac{C_o}{C_o - C_e} \cdot \frac{(C) - C_e}{(C)}$$

would result in a linear trend. Further, if Equation 10 holds for the stabilization stage of the reaction, the experimental results plotted as (C) against time after adsorption equilibrium has been reached would show a linear trend. It should be recognized at this point, however, that the fact that the experimental results fit the proposed hypothesis on the reaction kinetics does not prove that this is the only mechanism which would fit the data. It would, however, strengthen the evidence that the average mechanisms or kinetics of a heterogeneous reaction such as this can be predicted.

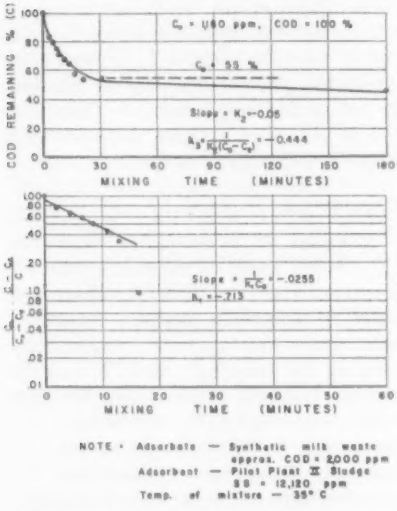

COD REMAINING, % (C)
C_o = 1,160 ppm, COD = 100 %
C_e = 55 %
Slope = K_2 = −0.05
$k_2 = K_2(C_o - C_e) = -0.444$
MIXING TIME (MINUTES)
Slope = $\frac{1}{K_1 C_o}$ = −.0255
K_1 = −.713
MIXING TIME (MINUTES)
NOTE : Adsorbate — Synthetic milk waste approx. COD = 2,000 ppm
Adsorbent — Pilot Plant II Sludge SS = 12,120 ppm
Temp. of mixture — 35° C

FIGURE 1.—Rate of adsorption and stabilization of dissolved organic matter by anaerobic sludge using synthetic milk waste with a COD of approximately 2,000 ppm and SS of 12,120 ppm.

The summary data for the experiments on adsorption and stabilization are shown in Table I. The temperature of the mixture in each case corresponded with the normal temperature

of the sludge used in pilot-plant operation. In all cases the COD of the waste was used as a measure of the adsorbate concentration. The k_1 and k_2 values were determined graphically from a plot of the experimental data in each test and are based on the per cent of COD remaining (C) at any instant. A small amount of the enzyme complex (CE^*) undoubtedly existed in the sludge samples used in the experiments. This was not measured and was neglected in computing the value of k_2 which assumed that at adsorption equilibrium, $CE^* = C_o - C_e$. Neglecting this factor may have caused some variations in the k_2 values and should be considered in further tests.

Typical graphical results together with other pertinent data are shown in Figures 1, 2, 3, and 4 for test numbers 7, 8, 11, and 12, respectively, as itemized in Table I. In addition to these tests, others showed fairly good agreement with the theoretical hypothesis on the adsorption and stabilization reactions. Although preliminary, an analysis of

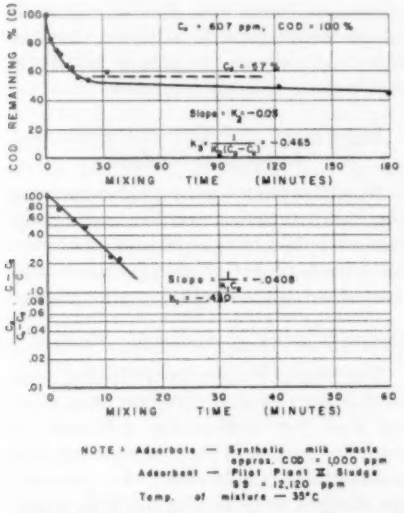

COD REMAINING % (C)
C_o = 607 ppm, COD = 100 %
C_e = 57 %
Slope = K_2 = -0.09
$k_2' \frac{1}{K_1(C_o - C_e)}$ = +0.465
MIXING TIME (MINUTES)
Slope = $\frac{1}{K_1 C_o}$ = -.0408
k_1 = -.490
NOTE : Adsorbate — Synthetic milk waste approx. COD = 1,000 ppm
Adsorbent — Pilot Plant Σ Sludge SS = 12,120 ppm
Temp. of mixture — 35°C

FIGURE 2.—Rate of adsorption and stabilization of dissolved organic matter by anaerobic sludge using synthetic milk waste with a COD of approximately 1,000 ppm and SS of 12,120 ppm.

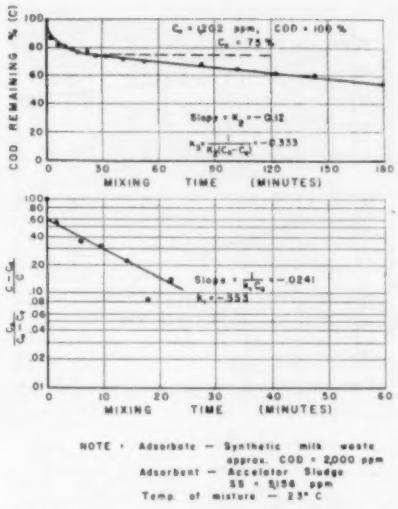

COD REMAINING % (C)
C_o = 1202 ppm, COD = 100 %
C_e = 75 %
Slope = K_2 = -0.12
$k_2' \frac{1}{K_1(C_o - C_e)}$ = -0.333
MIXING TIME (MINUTES)
Slope = $\frac{1}{K_1 C_o}$ = -.0241
k_1 = -.353
MIXING TIME (MINUTES)
NOTE : Adsorbate — Synthetic milk waste approx. COD = 2,000 ppm
Adsorbent — Accelator Sludge SS = 5,156 ppm
Temp. of mixture — 23° C

FIGURE 3.—Rate of adsorption and stabilization of organic matter by anaerobic sludge using synthetic milk waste with a COD of 2,000 ppm and SS of 5,156 ppm.

the results of these tests indicates several interesting points regarding the adsorption and stabilization of organic matter by anaerobic sludge.

The initial rapid uptake of organic matter from a waste followed by a much slower reaction was typical for all tests. The initial rapid reaction which has been called adsorption reached equilibrium in a period of 30 to 60 min after which the subsequent stabilization reaction progressed at a much slower and uniform rate. Graphical analysis of the results of the experiments indicated that the data would fit the proposed hypothesis in most cases. This can be seen in Figures 1 through 4. It is evident that within limits the initial adsorption reaction is described quite closely by Equation 7 and that the stabilization reaction tends to become linear and can be described by Equation 10. The velocity constants, k_1 and k_2, which were computed graphically for each test show substantial variation for the different tests. This would tend to indicate that the rate of reaction is af-

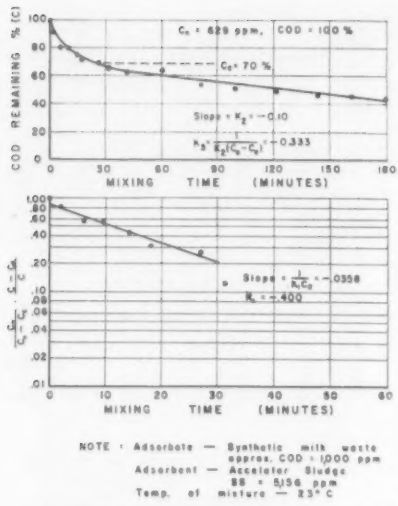

COD REMAINING % (C)
MIXING TIME (MINUTES)
Slope = K2 = -0.10
K3 = 0.333
Slope = 1/K1C0 = -0.058
K1 = 1.400
NOTE : Adsorbate — Synthetic milk waste approx. COD = 1,000 ppm
Adsorbent — Aeration Sludge SS = 5,156 ppm
Temp. of mixture — 23° C

FIGURE 4.—Rate of adsorption and stabilization of organic matter by anaerobic sludge using synthetic milk waste with a COD of 1,000 ppm and SS of 5,156 ppm.

fected by other factors than those which were controlled during the experiment. Among the factors which appear to be important are the previous history and condition of the sludge with respect to loading, type of feed, temperature, etc. Several tests indicated that the activity of the sludge varies with certain conditions; for instance sludge which was not fed for several months appeared to lose most of its adsorptive and stabilization capacity. Also, it was found that pasteurizing the sludge at 65°C for 20 min destroyed the activity of the sludge completely.

Apart from the fact that the experimental data appear to agree quite well with the Michaelis-Menten theory on the kinetics of enzyme reactions, the most important conclusion that can be drawn from the results of these experiments is that the absolute quantity of organic matter removed and stabilized by the sludge appears to be a direct function of the organic concentration of the raw wastes. This is evident from a comparison of Figures 1 and 2 which present the results of tests 7 and 8 using the same sludge at different adsorbate concentrations. Since the initial concentration of COD in the adsorbate sludge mixture is about one-half as much for test 8 as in test 7 and the percent COD remaining in the substrate at three hours is about the same, it is apparent that doubling the concentration of the adsorbate approximately doubles the amount of COD removed. In test 7 the total COD removed per gram of sludge solids after three hours reaction time was 0.10 g and for test 8 was 0.051 g. This same relation is approximately true for tests 11 and 12 which are shown in Figures 3 and 4.

An experiment was carried out to determine the rate and degree of reversibility of the adsorption reaction in order to evaluate the backward rate constant (k_2). A sample of active sludge was mixed with distilled water to determine if the diluted concentration of organic molecules in the substrate would shift the equilibrium to the left in Equation 2. The results of this experiment indicated that the backward or "desorption" rate under these conditions was almost negligible which would tend to indicate that the activated enzyme complex is relatively stable after it is once formed.

Separation and Concentration of Anaerobic Sludges

Investigations aimed at determining the characteristics and evaluating the factors influencing separation and concentration of active sludges were conducted using the operating pilot plants.

Characteristics of Anaerobic Sludges

The sludges developed during this pilot-plant research program were similar and yet sufficiently different to cause variations in their separating and concentrating behavior. In general, the sludges were almost black in color, appeared quite light and flocculent in nature, and as normally used in the pilot plants contained solids concentrations of 0.2 to 2.0 per cent. The solids

in the sludge tended to separate from the liquid portion on standing either by floating or settling. If the sludge was degasified under vacuum and allowed to stand quiescently, the solids would all tend to settle, at least until gas production caused subsequent gas lifting. In the range of solids concentrations normally used in the pilot-plant studies, this gravity separation process was characterized by a definite sludge-liquid interface, accompanied by a relatively clear supernatant. This function could be visualized as more of a thickening than a settling process.

Several studies were made on the sludges treating packing plant and milk wastes to determine the size distribution and specific gravity of the sludge floc. The size was measured by taking photographs of the sludge flocs settling through clear supernatant liquid. These measurements indicated a range in floc sizes from 0.10 to 2.80 mm and averaged 0.76 mm. The average of several tests to determine the specific gravity of the sludge particles which were developed during the pilot-plant tests on packing plant and milk wastes are shown in Table II. The very small difference in specific gravity between the sludge floc with entrained liquid and the suspending media would have a marked effect on the free fall subsidence velocity of the particles. However, this factor becomes even less important at the relatively high solids concentrations normally found in the anaerobic process.

Although the sludge volume index is not directly applicable to continuous flow separation, it is in a sense an arbitrary indicator of the concentration or separation character of the sludge solids. A number of quiescent settling tests were carried out on various sludges taken from the pilot plants to determine the effect of solids concentration on the rate of the solids interface lowering. The results of several typical tests of this type are shown in Figure 5. There are several interesting points which are demonstrated by these data: (a) the ability of the sludge to concentrate under quiescent settling conditions was apparently somewhat different for each of the test series shown, and (b) the rate of interface lowering in all cases appears to be a function of the initial solids concentration.

It was evident that the sludges developed under various pilot-plant operating conditions varied somewhat with respect to their ability to concentrate. This was especially true of the sludges developed when treating milk wastes. With packing plant wastes, the sludge volume index increased from about 50 in the early tests to an

TABLE II.—Results of Specific Gravity Tests of Packing Plant and Milk Wastes

Sludge Feed	Specific Gravity*			
	Dry Solids	Wet Solids	Effluent	Difference
Packing plant†	1.36	1.0163	1.0040	0.0123
Milk†	1.61	0.9996	0.9961	0.0035

* Compared to water at 4°C.
† Temperature 35°C.

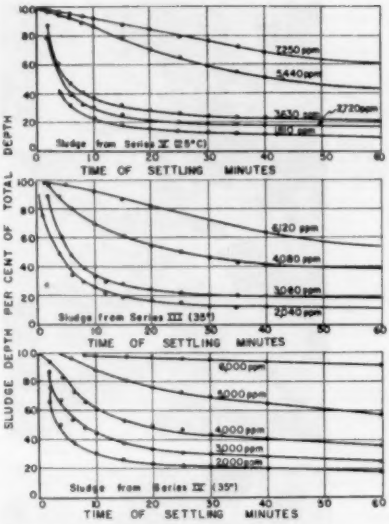


FIGURE 5.—Effect of suspended solids concentration on quiescent settling of anaerobic sludge.

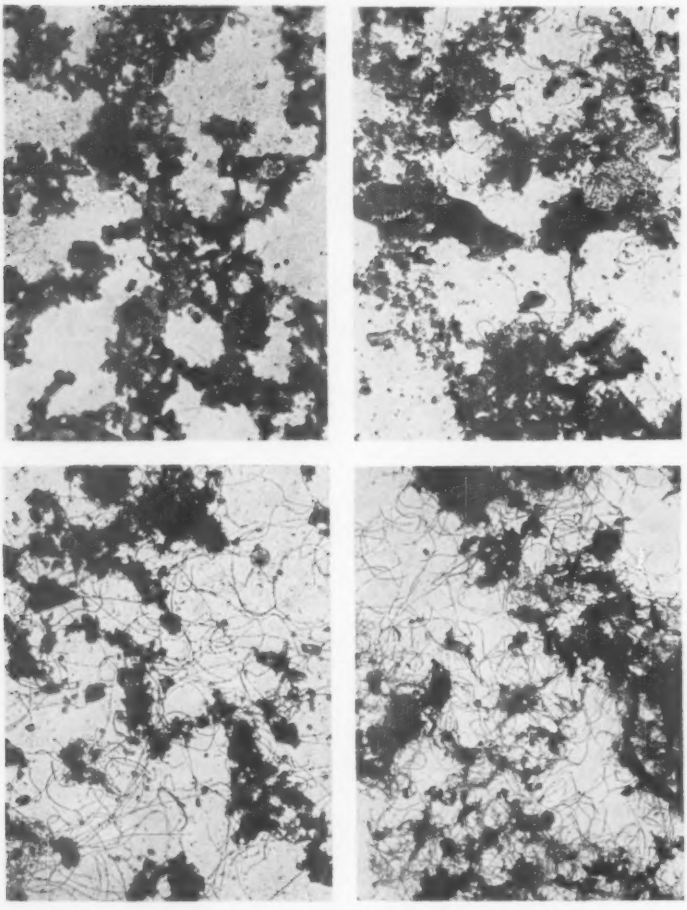


FIGURE 6.—Photomicrographs of anaerobic sludge showing progressive development of filamentous growth.

equilibrium value of about 100 during the remainder of the period. During the tests using synthetic milk wastes, the index increased progressively from 50 to over 300. At the high index the sludge was difficult to separate and would indicate a condition similar to "bulking" of activated sludge. The reason for this change in sludge character is not completely understood; however, it was noted that the sludges produced during the pilot-plant tests on synthetic milk waste developed a filamentous bacterial growth, especially at the higher loadings. It was felt that this growth contributed a great deal to the bulking of the sludge. The series of photomicrographs presented in Figure 6 show typical examples of the progressive development of this filamentous growth and its effect on the sludge volume index. Upper left shows seed sludge with a SVI of 26; upper right, sludge with SVI of 30; lower left, SVI of 102; and lower right, SVI of 166. Apparently this type of growth is caused by the environmental conditions provided for the sludge organisms

such as type of feed, loading, minerals, etc. This so-called bulking condition did not develop when actual plant wastes were used.

The data for the quiescent settling tests shown in Figure 5 can be used to demonstrate the existence of a definite hindered settling zone in the liquid-solids separation of anaerobic sludges. In Figure 7 the 8-min and 30-min sludge volume indexes have been plotted against the initial solids concentration for the settling tests shown in Figure 5. It is apparent from these results that there is an abrupt change in the concentrating characteristics of the sludge at a solids concentration of about 4,000 to 6,000 ppm, which would indicate that beyond this limiting concentration, the separation process is much slower which is caused by the interference of velocity fields between particles.

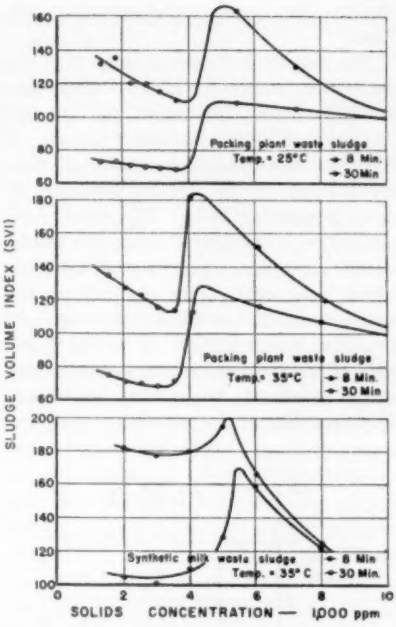


FIGURE 7.—Effect of initial solids concentration on sludge volume indexes of 8 and 30 min for tests shown in Figure 5.

Gravity Separation and Concentration

It should be pointed out that the problem of liquid solids separation at the relative high solids concentrations used in the pilot-plant studies is largely one of thickening rather than sedimentation, as usually considered. In this respect, it was felt that the factors governing the gravity separation of anaerobic sludges at the solids concentrations normally used in the pilot plants would be those which influence liquid solids separation in the so-called hindered settling and compaction zones.

A series of continuous flow separation studies was carried out on an anaerobic sludge which was developed at low loadings on synthetic milk waste. This was designed to study the effect of separator loading and return sludge rate on the equilibrium sludge depth and to determine solids concentration gradients in the separator under these various loading conditions.

Nine individual tests were carried out using various separator loading and operating conditions to determine the equilibrium solids concentration gradient in the separator and the effect of separator loading on sludge depth. These tests were made using a sludge culture which was being fed synthetic milk waste at a very low rate of BOD loading (0.02 lb/day/cu ft) in order to avoid gas lifting which might have obscured the separation results. The 30-min SVI for this sludge was measured at 200 just prior to the tests. The 4-in. diameter separator was equipped with sampling points every 4 in. in a depth of 5.67 ft in order to check the variation in solids concentration with depth. Insofar as possible, the inlet to the separator was placed at or slightly below the equilibrium sludge interface. In each test the separator was operated continuously under a fixed set of conditions until the equilibrium sludge depth was established. Samples were then taken from the sludge column at 4-in. intervals to de-

termine the solids concentration gradient.

The results indicate clearly that the separation occurred in two somewhat distinct zones. Although the concentration gradient diagrams shown in Figure 8 are somewhat idealized, they are typical of the results obtained in these separation tests. The solids concentration immediately below the solids-liquid interface was about 4,000 ppm which was arbitrarily defined as the upper limit of the hindered zone. At a solids concentration of about 7,500 ppm there is an observed discontinuity in the gradient, apparently indicating the beginning of the compaction zone.

Table III shows a compilation of surface overflow rates and solids characteristics for the four cases shown in Figure 8.

An analysis of the data taken during these tests was made in order to determine loading factors affecting the depth of the hindered zone and the compaction zone. The depth of the hindered zone was found to be a function of the separator loading. The effect of surface settling rate and solids applied rate on the hindered zone depth for six tests where solids did not overflow into the effluent are shown in Figure 9. It appears from these results that the depth of the hindered zone is a direct

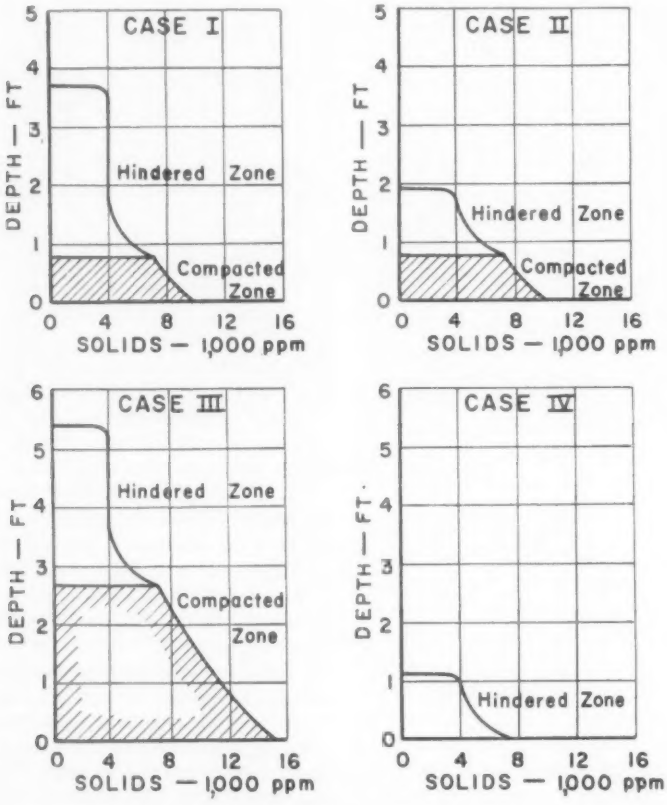


FIGURE 8.—Typical concentration gradient diagrams for various separator loading conditions.

TABLE III.—Surface Overflow Rates, Solids Loading and Return Sludge Ratio Data for the Cases Shown in Figure 8

Test Identification	Total Flow Surface Overflow Rate (gpd/sq ft)	Raw Flow Surface Overflow Rate (gpd/sq ft)	Suspended Solids Applied Rate (lb/day/sq ft)	Return Sludge Solids (ppm)	Influent Solids (ppm)	Return Sludge Ratio
Case I	500	250	20.8	10,000	5,000	1:1
Case II	250	125	10.4	10,000	5,000	1:1
Case III	500	333	20.8	15,000	5,000	5:1
Case IV	250	166	5.2	7,500	2,500	5:1

linear function of the total flow surface settling rate and the suspended solids applied rate. From the coefficient of correlation for the computed regression lines it would appear that the hindered depth is slightly more significantly related to the total flow surface settling rate. However, since all of the six tests where solids overflow did not occur were run at the same solids concentration and over a narrow loading range, it is possible that the solids applied rate is the significant factor and the effect of surface settling rate is only a secondary or dependent effect. In one of these tests, shown as an open point in Figure 9, the influent solids concentration was reduced by one-half. These data favor the premise that the surface settling rate is most significantly related to hindered depth.

The depth of the compaction zone was found to be a function of the degree of concentration necessary to maintain a solids balance between the influent and return sludge and this, in turn, was found to be a function of the return sludge ratio (return sludge flow divided by the effluent flow Q_{RS}/Q_{SE}).* The effect of solids concentration and return sludge ratio on the compaction zone depth are shown in Figure 10. It is apparent from these data that at equilibrium conditions, the compaction zone depth is a direct and linear function of the solids content of the return sludge. The computed line of regression shows excellent correlation with the data. The fact that equilibrium conditions were actually achieved during the tests is demonstrated by the close fit of the data to the theoretical solids balance curve shown at the bottom of Figure 10. The solids concentration ratio is the concentration of solids in the return sludge divided by solids concentration in the influent.

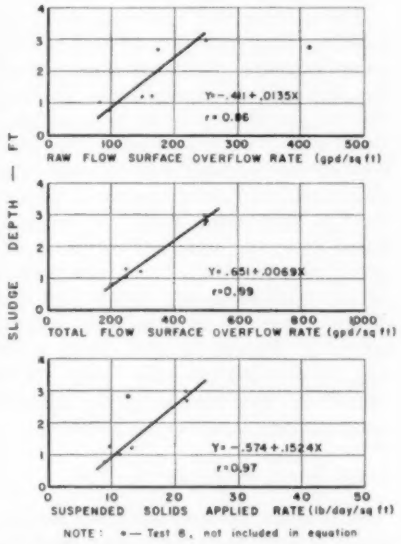


FIGURE 9.—Effect of separator loading on the hindered zone sludge depth (random point not included in line of regression).

* *Editor's Note*—Manual of Practice No. 6, "Units of Expression for Wastes and Wastes Treatment." FSIWA, Washington 16, D. C.; published in THIS JOURNAL, **30**, 5, 709 (May 1958), recommends that return sludge be expressed as per cent [100 × (return sludge flow/waste flow)].

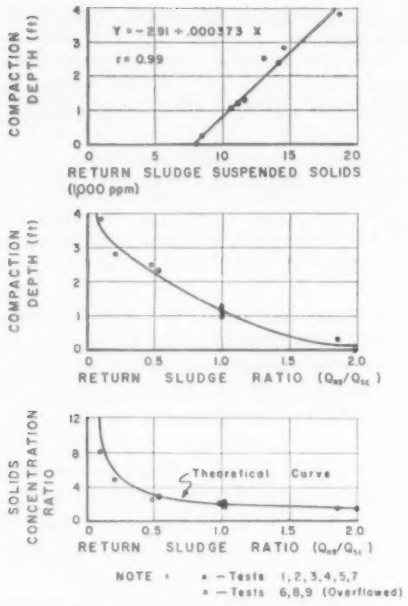

COMPACTION DEPTH (ft)
Y = -.291 + .000373 X
r = 0.99
RETURN SLUDGE SUSPENDED SOLIDS (1000 ppm)
COMPACTION DEPTH (ft)
RETURN SLUDGE RATIO (Q_{RS}/Q_{SC})
SOLIDS CONCENTRATION RATIO
Theoretical Curve
RETURN SLUDGE RATIO (Q_{RS}/Q_{SC})
NOTE : • — Tests 1, 2, 3, 4, 5, 7
○ — Tests 6, 8, 9 (Overflowed)

FIGURE 10.—Effect of return sludge ratio and suspended solids concentration on compacted zone depth.

The equations of the regression lines based on these data can be used to compute or predict the total sludge depth for any particular separator loading. The hindered depth can be computed, based either on the equation for total flow surface settling rate or suspended solids applied rate as shown in Figure 9. The compacted depth can be computed from the equation shown in the upper part of Figure 10. A comparison of the total measured depth with the depth computed on this basis is presented in Figure 11 and shows excellent correlation in each case. This procedure was also used for similar computations as shown in Figure 8.

Other Aids—Flotation

During the research program a number of preliminary tests were made to study the flotation process as a method of separating and concentrating anaerobic sludge. These tests were carried out on a batch basis using various proportions of pilot-plant effluent pressurized with air to 50.0 psi.

In general, the results of these tests showed that anaerobic sludge can be floated quite readily and to a fairly high degree of concentration. The concentration of the floated sludge appears to be a function of the character of the sludge as measured by the sludge index, the ratio of pressurized effluent to sludge, and the time allowed for concentration. Using a pressurized effluent to sludge ratio of two to one and a 30-min flotation period, the concentration of floated solids was about two or three times that which could be achieved by degasification and settling under usual conditions; i.e. 30,000 to 60,000 ppm. The effluent from the flotation process was rarely clear and in all cases contained appreciable settleable solids. This would indicate the need for a secondary separation unit following flotation, to recover the fraction of the solids necessary to the suc-

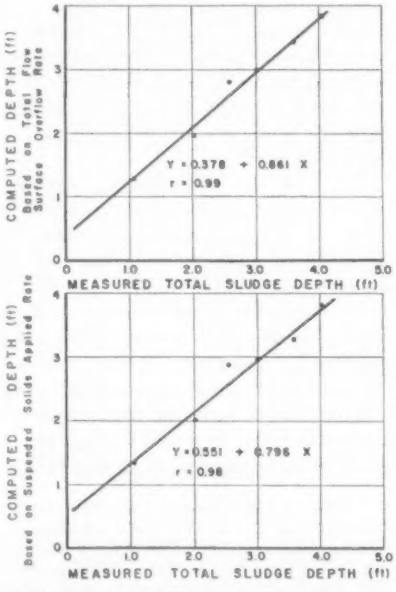

COMPUTED DEPTH (ft) Based on Total Flow Surface Overflow Rate
Y = 0.378 + 0.861 X
r = 0.99
MEASURED TOTAL SLUDGE DEPTH (ft)
COMPUTED DEPTH (ft) Based on Suspended Solids Applied Rate
Y = 0.551 + 0.796 X
r = 0.98
MEASURED TOTAL SLUDGE DEPTH (ft)

FIGURE 11.—Correlation between computed and measured sludge depth.

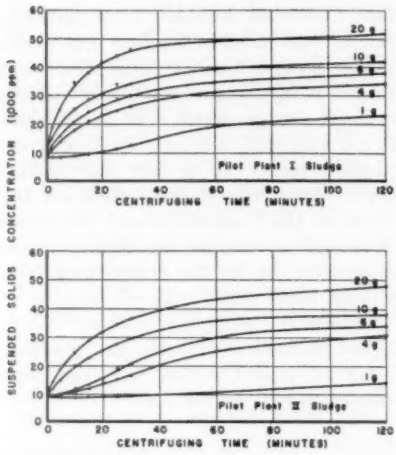


FIGURE 12.—Effect of centrifugal acceleration on concentration of anaerobic sludge.

cess of the process. Continuous flow studies of flotation are necessary to determine design and operational yardsticks before the effectiveness of this process as applied to anaerobic sludge can be established. This is indicated because in the normal operation gas entrainment is a necessary result.

Other Aids—Centrifuging

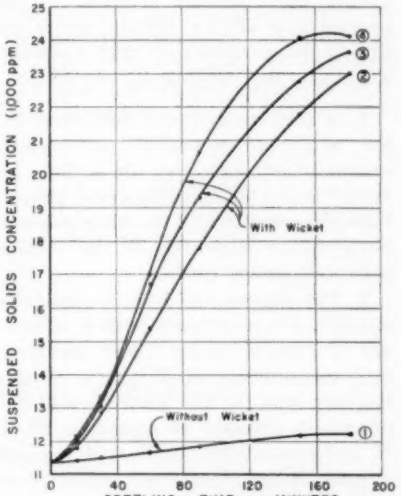
The effect of centrifugal force on the separation and concentration of anaerobic sludge was studied on a batch basis. Several samples of active sludge taken from pilot plants I and II treating synthetic milk waste at 35° and 25°C, respectively, were subjected to various centrifugal accelerations to determine the effect of this factor on the rate of concentration. The results of these tests are shown in Figure 12. These data indicate the following: (a) using relatively low centrifugal accelerations it is possible to increase the rate of concentration markedly over that obtained by gravity settling. Thus, the concentration accomplished in 2 hr of gravity settling ($1.0 \times g$) can be achieved in 15 min at $4.0 \times g$ and in less than 5 min at $20.0 \times g$; and (b) it is apparent that most of the concentrating effect occurs in the first 20 to 30 min.

No tests were carried out using continuous flow centrifuging because of the small scale of the pilot plants. However, the results of batch tests at low centrifugal accelerations appear promising.

Other Aids—Wicketing

A process of low rate stirring called "wicketing" has been used successfully in the past to enhance the thickening of concentrated sewage sludges.

Preliminary tests on a batch basis were made on a number of anaerobic sludges developed on synthetic milk waste to determine the effect of wicketing on the rate of solids concentration. In all cases it was shown that wicket action increased the rate of concentration appreciably. These tests were carried out in one-liter cylinders using screens of various mesh sizes as the


SUSPENDED SOLIDS CONCENTRATION (1000 ppm)
With Wicket
Without Wicket
SETTLING TIME — MINUTES
NOTE: Accelator Sludge — SVI = 86.8

Curve	Wicket Mesh Size – in.	Wicket Depth – %	Wicket Speed – RPM
1	None	—	—
2	½	60	0.9
3	¼	50	0.9
4	⅛	50	0.9

FIGURE 13.—Effect of wicket action on quiescent settling of anaerobic sludge.

wickets. Figure 13 shows the results for a typical experiment of this type. It is apparent that wicket action increases the rate of concentration of the solids. At two to three hours settling, solids concentration was almost twice that achieved without wicketing.

Encouraged by these results, several tests were made to determine the effect of wicket action in the continuous flow pilot-plant separation process. These tests were carried out in parallel separation tubes 4 ft deep, one as a control and one equipped with a wire mesh wicket. The results indicated only a slight decrease in sludge depth due to wicket action. This probably can be attributed to the fact that under the separator loading conditions and return sludge ratios used, most of the over-all sludge depth was in the hindered zone with a relatively small compaction zone. It is felt that wicket action has little if any effect on the depth of the hindered zone. The effect of wicket action in the higher solids concentrations in the compaction zone is most likely due to the elimination of "structural bridging effects" and liquid pockets in the sludge. Further study of wicket action including economics would be desirable.

Summary and Conclusions

The research program on the anaerobic treatment of wastewater conducted during the past three years has extended the application of the process to a number of different wastes and has contributed to a greater understanding of the basic actions involved in the process and of the factors which influence its performance and economy. The following conclusions are offered:

1. A process has been developed for the anaerobic treatment of organic wastes which separates the actions involved into a contact phase and separation phase and which in operation and performance is similar to the aerobic activated sludge process.

2. The process has been successfully applied on a pilot-plant basis to a number of organic wastes. For operation at a temperature of 35°C, the results indicate that for the wastes tested the process is capable of removing 80 to 95 per cent of the BOD load applied at contact unit loadings varying from 0.10 to 0.20 lb/day/cu ft.

3. The application of the process at lower temperatures is feasible at somewhat reduced loading. Tests on several wastes at a temperature of 25°C indicate that the process is capable of removing 80 to 90 per cent of the BOD load applied at contact unit loadings of 0.05 to 0.10 lb/day/cu ft.

4. The process appears to be adversely influenced by diurnal temperature variations of 10°C.

5. The importance of the thermal requirements of the process with respect to its economic application for waste treatment has been demonstrated. These results indicate the advantage of the process in treating relatively strong and warm wastes but do not preclude the possibility of the economic application of a modified anaerobic process to weaker and cooler wastes.

6. The solids concentrations maintained in the system were found to affect the economics of the process in that high solids concentrations were desirable in the contact portion of the process but were more difficult to separate in the separation portion. Accordingly, there appears to be an optimum solids concentration to best fit these requirements. In general, for the sludge developed during these tests, this optimum solids concentration appears to be near 12,000 ppm.

7. The anaerobic process appeared to be "rugged" enough to withstand the normal variations in waste quantity and strength. However, because of the

necessity of designing the separation process on a maximum flow basis, there appeared to be an economic advantage in providing for flow equalization, especially for extremes.

8. A process of degasification by the application of vacuum followed by gravity sedimentation was established as an efficient method of separating and concentrating anaerobic sludges. The results indicate that maximum separator loading to avoid sludge overflow is a function of the concentration and character of the sludge.

9. The surface overflow rate used in the four-foot separators during the pilot-plant tests ranged from 150 to 300 gpd/sq ft on a raw flow basis and 400 to 800 gpd/sq ft on a total flow basis. This corresponded to a solids loading range of 50 to 85 lb/day/sq ft for sludges developed on packing plant waste, (SVI of 50 to 100) and 25 to 35 lb/day/sq ft for sludges developed on milk waste (SVI of 100 to 300).

10. The relatively high removals which are possible by this process at loadings somewhat higher than are common in aerobic treatment can be explained partly by the temperature advantage and also by the fact that the suspended solids in the mixed liquor can be maintained at relatively high values (5,000 to 15,000 ppm).

11. The investigations of the anaerobic process made during this research program have indicated a number of possibilities for further improvement of the process. The need for further study in a number of important areas was also demonstrated. It is felt that continued studies should be made on these points so that the basic actions involved in the process can be fully understood and its potential as a waste treatment method realized.

Acknowledgments

The accomplishment of this project involved the efforts of a number of members of the sanitary engineering staff at the University of Minnesota in addition to the authors. Principal among these is A. S. Johnson, associate investigator for the first of the three-year program. The contribution of Sylvester Knapp, Paul Knopp, and Russell Susag as research assistants, and of other general student staff assistance is gratefully acknowledged. The use of the facilities and services of the University of Minnesota was essential to the proper execution of this program.

Reference

1. Michaelis, L., and Menten, M. L., *Biochem. Jour.*, **49**, 333 (1913).

NEW SEWER DESIGN MANUAL

The new Manual of Practice entitled "Design and Construction of Sanitary and Storm Sewers" is announced. This is the second publication produced by a joint FSIWA-ASCE committee in recent months. Again, comprehensive treatment of the subject is contained in the more than 300-page manual, under the chairmanship of Bernal Swab.

Orders are now being accepted for this FSIWA MOP No. 9 at $3.50 to members and $7.00 to others.

See page 260a for other publications and details for ordering.

DISPOSAL OF ALKALINE WASTES IN THE PETROCHEMICAL INDUSTRY *

By Alex D. McRae

Imperial Oil Limited, Sarnia, Ont., Canada

This is one of several papers from an Industrial Wastes Symposium titled, "The Petrochemical Industry." The first two papers were published in This Journal (**31**, 3, 274; and **31**, 5, 574). Other papers in the series will appear in early issues of This Journal.

Caustic alkali has been used in petroleum refining in the petrochemical industry since the inception of oil refining in the latter part of the nineteenth century. The chemical was known and used in soap making as early as the first century A.D. Originally it was produced by the action of lime on a solution of alkali carbonate derived from wood ashes, and consisted principally of sodium and potassium hydroxides heavily contaminated with impurities (1).

Some centuries later natural soda deposits were identified and worked by the Arabs in North Africa. From there soda found its way into Europe where, among other applications, it served in the preparation of caustic soda solutions. A good part of the caustic soda made today is produced by the electrolysis of sodium chloride. In tonnage it ranks second only to soda ash as an industrial alkali. It is delivered principally in the form of its water solution or in the several commercial anhydrous forms, such as solids, flakes, ground, and powdered. The petrochemical industry usually receives fresh caustic soda in tank cars. Solutions of up to 70 per cent sodium hydroxide are shipped in heated cars which have had the interiors nickel plated to minimize contamination from iron.

Use of Alkalies

Alkalies are used in the petrochemical industries to purify various hydrocarbon streams which range all the way from propane and butane to distillate fuel oils. This chemical treatment removes sulfur compounds, converts them to disulfides, and extracts unwanted compounds (such as phenols and other organic acids). The refiner utilizes many types of chemical treatment processes to yield products of high quality for the consumer. The by-products of some of these processes, however, produce waste materials which are difficult to dispose of without creating a stream pollution problem. Many methods for the disposal of spent caustic are known and available and selection usually hinges on the degree of treatment desired in order to comply with stream control regulations and air pollution restrictions.

Requirements for Acceptable Disposal

Disposal methods are chosen to meet quality requirements of the receiving waters. The main points (2) to consider are:

1. The caustic discharge must not exist in the stream in concentrations

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

which may be toxic to humans, animals, fish, or other aquatic life.

2. The waste material must not cause the receiving stream to exceed limitations for threshold taste and odor, chemical oxygen demand, total solids, pH, chlorides, sulfides, phenols, and other critical substances as required by regulatory agencies.

3. The material discharged must not cause unsightly discoloration or contain quantities of floating material.

Treatment Methods

Caustic soda in water solution is brought in contact with hydrocarbons by many types of treating towers which remove sulfides, light mercaptans, phenols, and acid oils. It is essential that hydrogen sulfide be removed from petroleum distillates which are to be used as a motor fuel or as feedstock to petrochemical units. Sulfur is considered a poison in many catalytic conversion processes and caustic soda is used to remove its last traces. A major portion of hydrogen sulfide is usually removed along with the lighter hydrocarbons such as propane. The lighter fractions eventually are scrubbed with amine hydrocarbons. This organic solvent can be regenerated with steam. There are several modifications of the caustic method for the treatment of hydrocarbons for removal of mercaptans and, in all of these, the spent alkalies can be regenerated with steam and sometimes by a combination of steam and air.

Regeneration of Spent Alkali

To prevent stream pollution and to conserve caustic soda, the spent alkali is regenerated whenever possible. There are many processes available for regeneration (3), including steam hydrolysis, use of nascent oxygen derived from electrolysis, air regeneration, and the use of slaked lime. The plant manager must try to select the most economical methods of regeneration while keeping in mind the restrictions on the ultimate discharge of the waste to the receiving waters. In the steam hydrolysis and air oxidation processes it is possible to regenerate approximately 90 per cent of the caustic soda by converting mercaptans to disulfides which are relatively insoluble in the recovered caustic and, therefore, can be removed. In the case of sulfides, it is possible to convert these compounds to polysulfides, elemental sulfur, or sodium thiosulfate. A 50 per cent conversion is possible in the case of sulfides but there will be a gradual buildup of thiosulfates, requiring ultimate discharge of the waste material. Some refiners have followed the practice of the paper companies which use alkalies for pulping and regenerate the spent alkali with hydrated lime after incineration to carbonate and sulfate. In some remote areas this practice is necessary because long rail hauls make the use of fresh caustic uneconomical while lime is readily available. The use of lime regeneration is also practiced in areas where water quality restrictions forbid the discharge of alkali-bearing wastes.

Regeneration by Steam Hydrolysis

Steam hydrolysis is the regeneration process used for treating the largest volume of spent caustic used by the industry. It is effective in removing light mercaptans but will not regenerate sulfides, naphthenates, or phenolates.

Figure 1 is a flow diagram for the steam regeneration process. Spent caustic containing mercaptans is charged to a treating tower in which a bottom temperature of 260°F is maintained by a re-boiler section. Steam injection is used to maintain a top vapor temperature of 235°F which is later reduced to 200°F by an overhead condenser. The mercaptans are hydrolyzed by the steam and pass overhead to a mercaptan stripper where they are volatilized and passed to a flare or furnace for incineration. The bottoms from this stripper are returned to the caustic stripping tower as reflux. The recov-

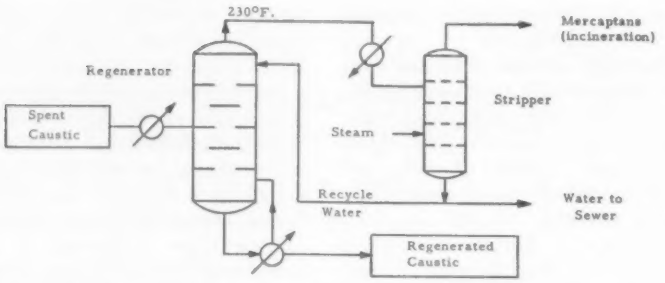


FIGURE 1.—Flow diagram for steam regeneration of spent caustic.

ered caustic is returned to the treating system for further use. The caustic stripping tower has to be lined with a resistant metal such as monel; otherwise severe corrosion takes place above 230°F. A gradual buildup of sulfides occurs in the recovered caustic and eventually it must be discarded.

Electrical Regeneration

In the electrical regeneration process it is claimed that spent caustic containing sodium sulfide can be oxidized at ambient temperatures. The oxidation process regenerates foul caustic and allows for its reuse. The regeneration of spent caustic through external oxidation has been employed commercially for some time. Caustics containing sodium hydrogen sulfide, when treated with atomic oxygen, will regenerate to free caustic and a sulfur complex. Usually small amounts of mercaptan sulfur in the system are converted to disulfides which absorb or react with free sulfur to form polysulfides. The polysulfides have some commercial value and are sold. The oxidation reactions are as follows:

$$2\,NaSR + H_2O + O = R_2S_2 + 2\,NaOH \quad (1)$$

$$Na_2S + H_2O + O = 2\,NaOH + S \quad (2)$$

$$R_2S_2 + S = R_2S_3 \quad (3)$$

where R represents the alkyl group and NaSR represents sodium mercaptide.

As shown in Figure 2, the electrical process consists of a commercial electrolizer for the generation of oxygen and hydrogen, an eductor for the injection and mixing of atomic oxygen, surge tanks, pumps, and necessary piping and instrumentation. The electrolizer is usually a unipolar tank-type cell operated at current strength up to

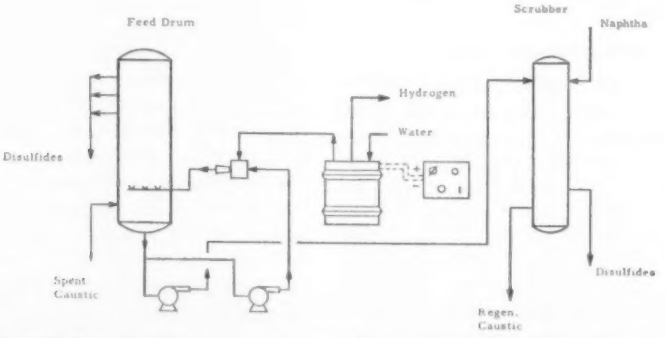


FIGURE 2.—Flow diagram for electrical regeneration of spent caustic.

10,000 amp. The cell tank contains eight electrodes constructed of nickel-plated iron. Each pair of anode and cathode plates is separated by an asbestos diaphragm. Oxygen collectors are mounted above the anode plates and hydrogen collectors are mounted above the cathode plates. Direct current power is supplied by a rectifier and the complete oxygen-generating equipment is housed in a pressurized building to eliminate hazards. Approximately 0.5 to 0.7 lb of sulfur per kilowatt will be oxidized with the electrical regeneration unit. Spent caustic is fed to an accumulating drum and then pumped to an eductor where atomic oxygen catalyzes and reacts with the sulfur-bearing caustic, resulting in the formation of free sodium hydroxide. The effluent from the eductor returns to the common surge drum. Sulfur and polysulfides are formed in the reaction and are separated by gravity and periodically removed from the foul-caustic tank. The regenerated caustic is returned to the treating unit for further use. Test results after 48 hr of operation are shown in Table I.

The electrolytic process is used in the petrochemical industry although it has been demonstrated that air oxidation will accomplish the same results with much less expenditure for equipment. Certain precautions must be taken because of the explosion hazard connected with the mixture of air and disulfide vapors. Disulfides removed are either burned in the vapor state or removed by naphtha and fed as a fuel product to the process units.

TABLE I.—Test Results from Electrical Regeneration of Spent Caustic

Item	Spent Caustic	Regenerated Caustic
Capacity (bbl/day)	140	140
Temperature (°F)	80	80
Pressure (psi)	50	0
Sulfide (moles/liter)	0.750	0.320
Mercaptan (moles/liter)	0.125	0.062
Free NaOH (moles/liter)	0.981	1.454

Spent Alkali Disposal

As mentioned above, spent alkali solutions contain organic acidic material, such as acid oils or phenols, as well as sulfides, mercaptides, sulfates, and sulfanates. This complex of compounds in solution is a possible source of water pollution from the standpoint of toxicity, oxygen consumption, taste, odor, and appearance. The process operator normally reduces the potency of the caustic by using caustic solutions partially spent as a pre-wash in other operations, such as scrubbing hydrogen sulfide from distillates and gases. In addition, certain types of caustic are used to control pH in various refinery operations. Examples are treatment of process water, treating condensates from steam stills, and desalting crude oil.

The first requirement for effective disposal is a well-planned system for handling the spent material. Tankage and lines to collect and transfer the solutions to the disposal site are required.

Direct Disposal Methods

Direct disposal is usually the cheapest method of handling spent alkali solutions. These methods include dilution, use of disposal ponds and disposal wells, and sale of spent solutions. In many cases, however, the direct method is sometimes not suitable because of geographical or geological limitations. Each locality presents its own problems and it is necessary to study the topography and sub-strata of the area in order to decide on the best method of disposal.

Controlled disposal of spent caustic into large bodies of water or large rivers, where dilution is almost infinite, is sometimes suitable. This is true when discharge may be effected to salt water lakes, brackish streams, or to the ocean. Discharge into fresh water which is used for domestic purposes

and recreation is certainly not recommended.

Disposal of spent caustic solutions to ponds is not strongly recommended in the literature. If adequate detention time is possible then a pond can be used with care; the spent waste being oxidized and stabilized by storage and eventually disposed of by dilution.

Under special local conditions, a disposal well may be used. Using this method, spent caustic solutions are pumped into underground strata that contain brackish or saline water. Before this method can be adopted, however, it is necessary that the geological structure of the area be carefully explored. A structure of dolomite, limestone, or sandstone is required with a porosity of at least 10 per cent. The brine from the strata also must be analyzed to determine its compatibility with the spent solution since the precipitates formed may reduce the capacity and the life of the well. Any areas containing potable water must be isolated by casing the well and cementing at the point of injection. The cost of drilling such a well varies according to the nature of the terrain and the depth to which the well must be sunk. Several companies in the United States are using injection wells, however, and have been generally successful in disposing of wastes in this manner.

Sale of Spent Alkalies

Spent solutions containing sulfides, phenolates, cresolates, and some carbonates are salable. The cost of transportation must be taken into account and also the fact that the spent solution is usually sold in concentrated form with a range of gravities from 20 to 45°Bé. Some refiners are using electrical coalescing equipment in order to hold the gravity of the caustic solution to at least 45°Bé (approximately 50 per cent caustic). A third layer of sodium cresolates is formed after contact with petroleum distillates and this concentrated solution contains up to 50 per cent salable cresols. The production of cresols from petroleum and petrochemical manufacture has increased from 9 million lb in 1948, to 48 million lb in 1957. It is apparent that petroleum-derived cresylic acids have become an important commerical product over the past ten years. The total quantity in use is now almost double the quantity of imported acids used. With improved continuous-solvent extraction processes, sulfur and neutral oil pollutants can be removed efficiently and the resultant acids are now considered to be equal in quality to the imported products and to the best coal-tar-derived acids. The processing plants handling cresols now draw on supplies from practically every oil refinery in the United States and Canada when the material is available and of satisfactory quality.

Neutralization with Spent Acid

Acidic wastes are sometimes used as neutralizing agents for spent alkali solutions (Figure 3); sulfuric acid being

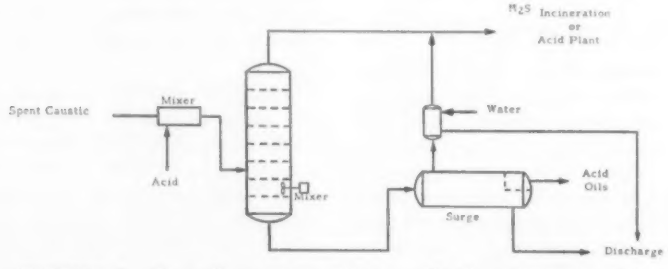


FIGURE 3.—Flow diagram for acid neutralization of spent caustic.

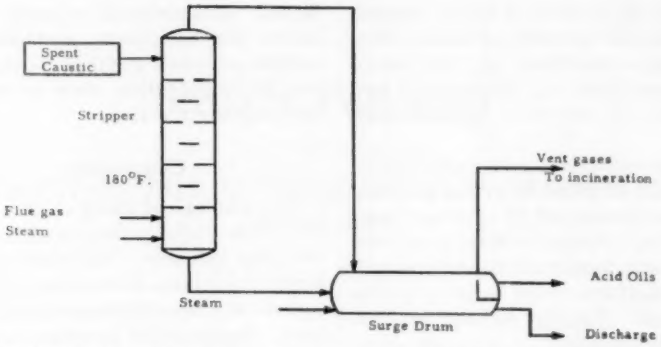


FIGURE 4.—Flow diagram for flue-gas neutralization of spent caustic.

the most widely used for this purpose. Acid sludges are usually hydrolyzed first before they are used as neutralizing agents. Acid oils are released and the evolved hydrogen sulfide incinerated during the neutralization process. It is sometimes necessary to steam-strip the neutralized solution before discharging it to the receiving waters. If maximum reduction of phenolic compounds is necessary, the neutralized solution requires additional treatment, such as biological oxidation.

Neutralization with Carbon Dioxide

Caustic can be neutralized by the carbon dioxide in flue gas which changes free hydroxide to carbonate (Figure 4). Sulfides, phenolates, mercaptides, or other basic salts are present in the solution as ions and these react with the carbon dioxide to form free hydrogen sulfide, phenols, and mercaptans. Such compounds may be recovered or disposed of as mentioned previously.

Flue-gas neutralization is practicable when the gas can be obtained from certain units during catalyst regeneration. If the pressure is sufficient to force the flue gas through a column or tank the application is feasible. Usually the temperature of the gas is above 600°F and therefore the formation of corrosive condensation products is not a problem which is likely to be encountered. A common design is a batch operation in which the spent solution is pumped from a collecting tank to the top of a packed or baffled tower. From there it flows downward, counter-current to the movement of the flue gas. The solution is recycled until carbonization is complete. The time required for complete carbonization varies from a

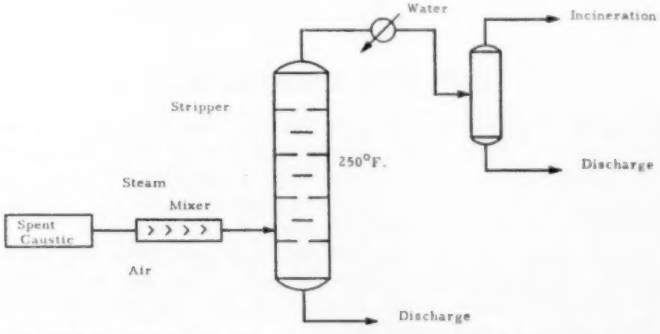


FIGURE 5.—Flow diagram for steam and air oxidation of spent caustic.

few hours to as much as 60 hr, depending on (a) the quantity of caustic solution being neutralized; (b) the rate of the flue-gas flow; (c) efficiency of contact; and (d) degree of carbonization desired.

A conservative design allows for a reaction time of 16 to 24 hr for a carbon dioxide utilization of 25 to 50 per cent. The treated solution contains a mixture of carbonates, bicarbonates, sulfates, sulfites, biosulfates, and some phenolic compounds. Usually further neutralization is required if phenolic compounds are a problem when discharged to receiving waters. Neutralization is necessary in order to enhance biological activity in an activated sludge or trickling filter plant.

Oxidation with Air and Steam

Several refiners reportedly have been successful in handling spent caustic through oxidation with air and steam (Figure 5). Gothard and Fowler (4) described the process and stated that 95 per cent of the sulfide-sulfur can be converted to the much less objectionable thiosulfate. This method of disposal has found widespread use on the West Coast and the refineries which use it claim that it meets their needs.

The equipment consists of a charge tank, a mixer, tower, heat exchanger, gas separator, pump, and other necessary piping and instrumentation. The reaction is carried out at 250°F and 50 psi. This makes it necessary to construct the equipment containing the sulfides of monel metal or its equal. A 5-to-10-hr detention time is required for complete reaction.

Conclusions

The disposal of spent caustic soda is one of the major problems of the petrochemical industry. The plant manager must, at all times, be cognizant of stream control and air pollution regulations or laws. Regenerative processes are necessary for conservation and to reduce the quantity of alkali which will ultimately be removed. The sale of spent chemicals has brought a measure of relief to the cost problem and the industry is studying alternate methods of treatment for further conservation of chemicals.

References

1. "Caustic Soda." Solvay Technical Bulletin No. 1. Allied Chemical Corp., Solvay Process Division, New York, N. Y.
2. "Manual on Disposal of Refinery Wastes." Vol. III. American Petroleum Institute, New York, N. Y. (1958).
3. Zandona, O. J., and Messinger, C. H., "Disposal of Spent Caustic Solutions." Ohio River Valley Water Sanitation Commission, Cincinnati, Ohio (Oct. 1, 1954).
4. Gothard, N. J., and Fowler, J. A., "Petroleum Refineries Pollution Abatement at Sinclair Refining Company." *Ind. Eng. Chem.*, **44**, 503 (1952).

INDUSTRY ON PARADE

Two recent issues of "Industry on Parade," the National Association of Manufacturers' weekly television series, have been featuring conservation of natural resources and reclamation of industrial wastes. These 15-min filmed documentary programs are telecast regularly by 270 television stations in the United States and some 40 stations abroad.

Prints of these two films are available for loan from the National Association of Manufacturers Film Library. They are also available now for sale from Arthur Lodge Productions, Inc., 21 West 46th Street, New York 36, N. Y., at $35 per unit.

Stream Pollution

ESTIMATING THE UPTAKE OF RADIOACTIVITY IN STREAMS

By Eugene K. Harris

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In 1954 a detailed report was issued on a survey of radioactivity (chiefly gross beta activity) in the Columbia River during the years 1951 through 1953 (1). Much of the effort expended in this survey was devoted to sampling aquatic life (plankton, algae, invertebrates, and fish) in order to measure the amount of radioactivity per unit weight of plant or animal tissue.

Biological sampling of this sort is necessary to locate radioactive materials removed from the stream by uptake (bioabsorption and adsorption) or deposition. However, such sampling cannot by itself provide estimates of the proportion of effluent radioactivity removed by these processes (as compared with that removed by natural decay). Therefore, the capacity of the stream to absorb the radioactivity it receives, cannot be estimated in this way. In order to make such an estimate, total weights of various types of biotic tissue in the stream would be required to obtain corrective factors for the observed concentrations.

The purpose of this paper is to show how, by simple statistical methods, much information about uptake or deposition of radioactivity may be gained from examination of water samples alone. Findings in the Columbia River study will serve to illustrate the procedures. Practical application of these methods is limited to effluents containing short-lived radionuclides in which substantial natural decay may be expected during periods of flow measured in hours. Such wastes may arise (as they did in the Columbia River) through neutron bombardment of dissolved and suspended materials in cooling water.

Methods

Basic Stream Conditions

Radioactive effluents as cited have two general characteristics: (a) they often represent a mixture of radionuclides with differing decay rates; and (b) the over-all concentration of radioactivity varies from day to day, although the relative concentrations of specific nuclides remain fairly constant if elements normally present in the stream do not vary greatly.

The first characteristic implies that the concentration of total activity in the effluent after time t, assuming no loss except through decay, may be written:

$$C_t = C_{01}e^{-k_1 t} + C_{02}e^{-k_2 t} + \cdots + C_{0n}e^{-k_n t} = \sum_{i=1}^{n} C_{0i}e^{-k_i t} \quad (1)$$

where C_{0i} represents the initial concentration and k_i the decay rate of the i-th nuclide.

This formula requires either knowledge of the relative concentrations of all the nuclides in the mixture—parameters on which there may be incomplete information—or that, knowing the number n of such nuclides, estimates are made of the decay rates

and concentrations through calculations demanding high-speed computing equipment if n is greater than 4 or 5. Cornell (2) discussed this procedure. Moreover, it is commonly observed that the coefficient of variation in day-to-day radioactivity at sampling points along a stream remains fairly stable from one point to another and independent of the continual reduction in activity with increasing times of flow. This implies that the variance of log C_t will be homogeneous over time and independent of the mean log, a useful property in statistical tests. Clearly, Equation 1 is not suitable for taking logarithms.

Average Decay Rate

Next may be considered the average decay rate in a mixture of nuclides, recognizing that this average will decrease with time as the relative concentrations of short-lived nuclides become less and less. Denoting this decay rate function by $k(\tau)$ the concentration of total radioactivity may be expressed as

$$C_t = C_0 e^{-\int_0^t k(\tau)d\tau} \quad \ldots\ldots (2)$$

or

$$\log_e C_t = \log_e C_0 - \int_0^t k(\tau)d\tau \ldots (3)$$

and

$$E \log C_t = E \log C_0 - \int_0^{Et} k(\tau)d\tau \ldots (4)$$

where E stands for the expected or mean value of, say, daily measurements. By virtue of the rule on expected values of sums or differences, Equation 4 holds regardless of whether C_0 and t are correlated, another advantage of the logarithmic form. Such correlation would arise if the input of radioactivity were deliberately varied according to changes in stream discharge rates which would affect the mean time of flow to a given sampling point.

The theoretical difference between the logarithms of total activity at two points with mean times of flow $\bar{t}_1$ and $\bar{t}_2$ from the origin, assuming no loss except through natural decay, is given by the equation

$$E\,D(t_1,t_2) = \int_{\bar{t}_1}^{\bar{t}_2} k(\tau)d\tau \ldots\ldots (5)$$

Apart from any correction for dilution downstream, an observed difference significantly higher than this theoretical value indicates loss of activity through uptake or deposition in the stretch between the two points. Inspection of these differences at successive points downstream will indicate whether the longer-lived nuclides in the mixture are being taken up in appreciable quantities. Long-term study may reveal general trends such as might occur if the stream possessed only a limited capacity to absorb radioactive materials.

Further Steps

The next step is to select a suitable form for $k(\tau)$. A simple yet reasonable expression is provided by the modified exponential

$$k(\tau) = k' + ce^{-a\tau} \ldots\ldots (6)$$

which is asymptotic to k', the decay rate of the longest-lived nuclide in the mixture. Substituting Equation 6 into Equation 3 and integrating,

$$\log C_t = \log C_0 - k't - (c/a)(1 - e^{-at}) \ldots (7)$$

The parameters k', c, and a may be estimated from values of C_t/C_0 (or C_0/C_t) obtained by observing the decay in a representative water sample taken at the outfall of the reactor effluent. However, inserting these estimates into Equation 5 to determine loss of radioactivity through decay between two downstream points involves a tacit assumption, namely, that any uptake downstream does not alter the decay pattern of the effluent. In other words, such uptake is assumed to be nonselective, leaving essentially unchanged the relative concentrations

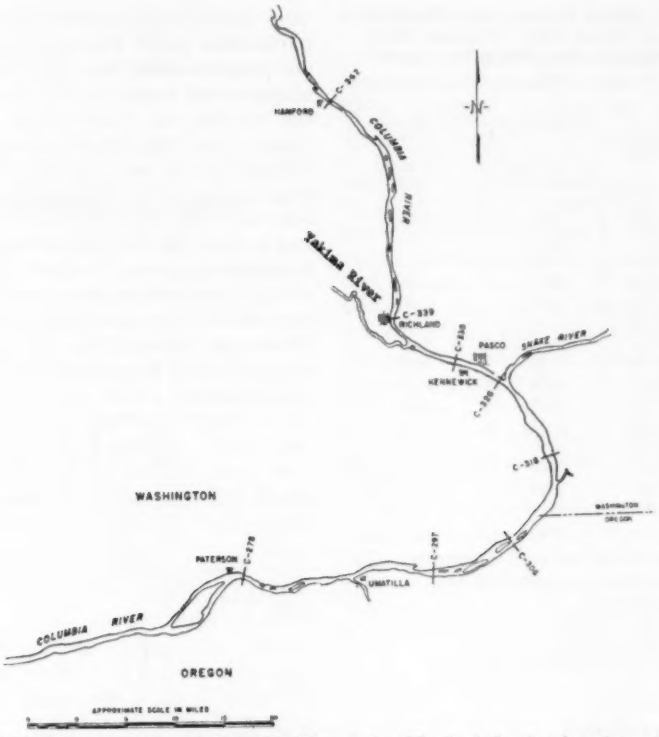

FIGURE 1.—Section of Columbia River below Hanford showing locations of sampling stations and tributaries.

of the nuclides in the water.* As illustrated below, this assumption may be checked by examining initial decay rates in samples taken at each of the downstream points.

Returning to Equation 7 it might be expected that k' would be known beforehand and not require estimation. However, unless the decay has been observed for a period of time approaching the half-life represented by this value of k', the estimation procedure will yield a larger value, closer to the average k at the longest observed time. The goodness of fit of Equation 7 will therefore be impaired unless k' is left free to be estimated from the data.

* Some minor variation in these relative concentrations will occur, but these are not likely to affect significantly the observed decay pattern.

Assuming that many, if not all, of the concentrations C_t are measured at equal intervals of time,

$$y_t = \log_e C_t - \log_e C_{t+m} = mk' + \frac{c}{a}(1 - e^{-ma})e^{-at} \quad . . (8)$$

Equation 8 is a modified exponential of the general form: $y_t = \alpha_0 + \alpha_1 e^{-at}$. Recently, Cornell (2) has developed a new procedure for estimating the parameters of linear combinations of exponentials, of which Equation 8 is a simple example. Cornell's formulas are applied in the next section.

Substituting Equation 6, with estimated parameters, into Equation 5,

$$E\,D(t_1,t_2) = k'(\bar{t}_2 - \bar{t}_1) + \frac{c}{a}(e^{-a\bar{t}_1} - e^{-a\bar{t}_2}) \quad . . (9)$$

TABLE I.—Decay Factors, C_0/C_t, Measured in Water at Station C-362, Columbia River, and Estimated by Fitting Equation 7

Time (hr)	C_0/C_t Observed*	C_0/C_t (Estimated by Fitting Equation 7)	
		First 9 Hourly Observations†	5-hr Data‡ ($t = 0, 5, 10, \cdots 30$)
0	1.00	1.00	1.00
1	1.11	1.12	1.09
2	1.22	1.24	1.18
3	1.34	1.34	1.27
4	1.44	1.43	1.36
5	1.52	1.52	1.46
6	1.61	1.61	1.55
7	1.70	1.69	1.65
8	1.79	1.78	1.74
9	1.86	1.86	1.84
10	1.94	1.94	1.94
15	2.40	2.40	2.45
20	2.98	2.95	2.98
25	3.53	3.62	3.55
30	4.17	4.44	4.17

* Source: Table A-1 in Reference (1).
† $\hat{k}' = 0.04083$ (17.0-hr half-life)
$\hat{a} = 0.34185$
$\hat{c}/\hat{a} = 0.26530$
$\hat{c} = 0.09069$.
‡ $\hat{k}' = 0.02739$ (25.3-hr half-life)
$\hat{a} = 0.09178$
$\hat{c}/\hat{a} = 0.64725$
$\hat{c} = 0.05940$.

Discussion of Decay Factors

Figure 1 outlines the appropriate section of the Columbia River, locating sampling stations and major tributary streams. Table I lists observed values of C_0/C_t, as reported by Robeck *et al.* (1), representing the decay in a water sample taken at Range C-362, a sampling station just below the outfall of the farthest downstream reactor at the Hanford Works. Column 3 lists computed values of C_0/C_t obtained by fitting Equation 8 to the hourly observations ($m = 1$) through 10 hr (i.e., through $t = 9$). Similarly, Column 4 lists values obtained by fitting this equation to the observations at $t = 0$, 5, 10, 15, 20, 25, and 30 hr ($m = 5$). The estimates of the parameters are given below the respective columns.

Cornell's estimation procedure calls for dividing equally spaced observations into as many groups as there are parameters to be estimated. If there are p parameters, the total number of observations must be np, where n is the number of observations in each group. For the hourly observations through $t = 9$, $np = 9$ (i.e., 9 values of y_t) and $n = 3$. Taking the data at 5-hr intervals through $t = 30$, $np = 6$ and $n = 2$. In the case of the modified exponential, $y_t = \alpha_0 + \alpha_1 e^{-at}$, the totals of the observations are computed for each of the three groups in succession. These are labeled S_1, S_2, and S_3, respectively. The estimation formulas are as follows:

$$\hat{a} = -\frac{1}{nK} \log_e \left(\frac{S_2 - S_3}{S_1 - S_2} \right),$$

where K is the interval between observations,

$$\hat{\alpha}_0 = \frac{S_1 S_3 - S_2^2}{n(S_1 - 2S_2 + S_3)},$$

and

$$\hat{\alpha}_1 = \frac{(S_1 - S_2)^3 \left[1 - \left(\frac{S_2 - S_3}{S_1 - S_2} \right)^{1/n} \right]}{(S_1 - 2S_2 + S_3)^2}.$$

Referring to Equation 8, $\hat{\alpha}_0$ is an estimate of mk' and $\hat{\alpha}_1$ an estimate of $\frac{c}{a}(1 - e^{-ma})$.

For example, using a table of common logarithms, values of y_t based on the first 10 hourly determinations (Table I) gave

$$S_1 = 0.0453 + 0.0411 + 0.0407 = 0.1271,$$

$$S_2 = 0.0313 + 0.0234 + 0.0250 = 0.0797,$$

$$S_3 = 0.0236 + 0.0224 + 0.0167 = 0.0627,$$

$$\hat{a} = -1/3 \left(2.30259 \log_{10} \frac{0.0170}{0.0474} \right) = 0.342,$$

$$\hat{\alpha}_0 = \frac{0.00161708}{3(0.0304)} = 0.0177,$$

$$\hat{k}' = 2.30259\, \hat{\alpha}_0 = 0.0408$$

(or a half-life of 17.0 hr),

$$\hat{\alpha}_1 = \frac{0.00010650(1 - 0.7105)}{0.00092416} = 0.0334,$$

and

$$\frac{\hat{c}}{\hat{a}} = \frac{2.30259\ \hat{a}_1}{1 - e^{-\hat{a}}} = 0.265.$$

Then

$$\hat{E}\ (C_0/C_t) = e^{\hat{k}'t + (\hat{c}/\hat{a})(1-e^{-\hat{a}t})}. \quad (10)$$

Verification of Assumptions

Equation 1 with estimates obtained from the first 10 measurements of C_0/C_t shows excellent fit not only to these points but also to $t = 15$ and 20 hr. At $t = 25$ and 30, it reveals an increasing divergence from the data as a result of too rapid a decay pattern produced by too high an estimate of k', the ultimate decay rate. When the parameters are estimated from five-hourly data ($t = 0, 5, 10, \cdots 30$), the fit is seen to be very good for $10 \leq t \leq 30$ but worse for $t < 10$.

Taking observations at short intervals during the early, rapidly changing portion of the decay curve and at longer intervals during the flatter portion of the curve is common practice. It is not surprising that in order to achieve a good fit to a multi-nuclide decay pattern, using a mathematical model based on the relatively simple function expressed in Equation 6, a separate set of parameter values is required for each portion of the curve. A practical worker might question the worth of fitting two mathematical curves to define a series of observations that may easily be joined with a smooth curve drawn by eye. The purpose of the model, however, is not merely to estimate C_0/C_t for a given time of flow. It also provides (a) a test of the assumption noted earlier that the decay pattern in the outfall satisfactorily represents the natural decay occurring downstream (i.e., a test for selectivity of uptake) and (b) a ready means of measuring long-term variations in the effluent mixture through variation in the parameters k', a, and c as estimated from, say, 10-hr decay patterns observed at weekly or monthly intervals.

Test for Selectivity of Uptake

Before proceeding to estimate the uptake of radioactivity in the Columbia River, it is well to check this assumption concerning the representativeness of the decay pattern at the initial sampling point, Station C-362. Fortunately, decay factors C_0/C_t were determined from samples at each downstream station except C-306. For each such sample, only the decay rate at zero time, the time of collection, is of interest. This value, say k_0, will then be compared with $k(t)$ obtained from Equation 6 using the data at Station C-362 and substituting for τ the average time of flow from C-362 to the given downstream station.

Estimates of k_0 may be obtained by fitting the single-nuclide function, $k(\tau) = k_0$, or $C_0/C_t = e^{k_0 t}$ to the first few hours' decay at stations below C-362. This simple formula described very well the observed decay through the first 10 hr at these stations. Estimates of k_0 were derived from the least-squares equation,

$$k_0 = 2.30259 \left[\frac{\sum_{t=0}^{10} t x_t}{\sum t^2} \right],$$

where x_t denotes $\log_{10} C_0/C_t$.

Table II lists these values of k_0 by station together with $k(t)$-values obtained from Equation 6, using in some cases the two sets of estimates of the parameters: Set 1 based on hourly decay factors at Station C-362, and Set 2 based on factors measured at 5-hr intervals (see Columns 3 and 4 of Table I).

Goodness of Fit

This tabulation indicates that Equation 6, fitted to decay factors measured at Station C-362, represents fairly well the actual downstream decay provided suitable estimates are used for the parameters: Set 1 for times of flow of less than 10 hr, and Set 2 for those greater than 10 hr. This agrees in

TABLE II.—Comparison of Initial Decay Rates Observed at Downstream Stations and Estimated Rates from Decay Pattern at Outfall (Station C-362)

Station	Mean Time of Flow from C-362 During Sept.–May (hr)	Initial Decay Rate, k_0	Estimated Rate, $k(t)$, Based on:	
			Hourly Decay Factors	5-hr Decay Factors
C-339	7.5	0.050	0.048	0.057
C-330	10.8	0.048	0.043	0.049
C-326	12.5	0.045	0.042	0.046
C-316	17.5	0.037	—	0.039
C-306	22.5	no data	—	0.035
C-278	35.5	0.026	—	0.030

general with the goodness of fit noted in Table I.

More specifically, this analysis has not detected any significant selectivity in uptake during the first 30 to 35 hr of effluent time of flow from Station C-362. Of course, the possibility cannot be entirely ruled out that a certain amount of selection may have occurred with respect to some relatively long-lived nuclide, such as P^{32}, present in the effluent to a very small extent (less than 2 per cent in the case of P^{32}, according to Robeck *et al.* (1)). Such a situation would reveal itself more clearly at stations farther downstream, and this may explain the slight, but noticeable, divergence between calculated $k(t)$ and observed k_0 at Station C-316 and below.

Other Discussion

It should be pointed out that calculation of $k(t)$ for Station C-278 involves an extrapolation of Equation 6 beyond the range of the decay pattern from which its parameters were estimated. Such extrapolation may be expected to reveal some upward bias in the estimate of k', explaining, in part at least, the deviation between $k(t)$ and k_0 at this station. In any case, this deviation produces only a negligible difference in the estimated activity lost through decay. It is a reminder, however, that for reliable prediction the effluent decay pattern should be observed at least as long as the longest time of flow of interest downstream.

When substantial selectivity in uptake or deposition is found between two sampling stations, theoretical decay is difficult to estimate because the relative concentrations have been changing continually through the interval. One method might be to average the estimate obtained from the decay pattern at the first station with that based on the decay observed at the second station. The existence of selective uptake farther downstream must then be tested by referral to the latter decay pattern. Of course, any such additional downstream selectivity would necessarily be of a new type, and it seems unlikely that a succession of different types of selective absorption of radioactivity actually occurs in practice. In most situations, once the over-all process has been revealed through pilot study of effluent and downstream decay patterns, it should not be necessary to determine such patterns routinely at more than one downstream station.

Estimating Uptake During the Columbia River Survey

Turning now to the activity observed in Columbia River water, it was first desirable to separate data collected during the period of September 1 to May 1 from those collected during May through August. In the former season, discharge rates in the Columbia River remained at an almost constant level of 80,000 cfs. Starting in May, these rates rose sharply to a peak of close to

400,000 cfs and then gradually declined to their former level. In addition, mixing was not yet complete at the "initial" station, C-362, as evidenced in the report by declining activity levels farther across the river than 800 ft from the left (effluent) shore, facing upstream. At downstream Stations C-339, C-330, and C-326, activity levels were uniform across the stream. To eliminate bias due to incomplete mixing, results across the stream should be averaged at each of these four stations. However, at Station C-362, an unweighted average, which assumes that the volume of water discharged was constant across the stream, would underestimate the effluent activity, since the bulk of the water is known to pass closer to the left shore. As a compromise, declining weights (1.0, 0.8, 0.6, 0.4, and 0.2) have been applied to the results at the five sampling locations of Station C-362 in order of increasing distance from the left shore. At C-339, C-330, and C-326, where mixing was essentially complete, the problem of varying discharges across the stream is not important to this analysis.

Tributary Streams Effects

Tributary streams, in this case the Yakima and Snake Rivers, may present additional complications. Both these streams were essentially free of radioactivity during the survey period. The Yakima River joins the Columbia River below Station C-339 (Richland, Wash.) and adds about 5 per cent dilution. On this account all activity levels at Station C-330 and below should be adjusted by dividing by 0.95.

The effect of the Snake River is more difficult to deal with. This stream joins the Columbia River just below Station C-326, but rather than immediately mixing with the latter, it appears to push Columbia River water toward the left shore. During the low flow season (September to May), activity densities at Station C-316 showed little variation with distance up to 1,500 ft from this shore. Beyond this point activity levels dropped off sharply. Therefore, it was assumed that for these months average densities at this station measured through 1,500 ft were not affected by dilution from the Snake River.

During the high flow season at Station C-316, mixing of Snake River and Columbia River waters occurred to a greater extent, although there was again a decline in activity beyond 1,500 ft from the left shore. A 7-per cent factor, assigned to the average density through 1,500 ft at Station C-316 during the May to September season seemed reasonable to account for dilution at this point by the Snake River. This factor was indicated by the data at this station taken in conjunction with an approximate one-third dilution provided by the Snake River in summer at Station C-278 where the two streams were completely mixed.

By the time Station C-306 was reached considerable mixing of the rivers had occurred. However, at this station only five activity measurements were made beyond 1,400 ft from the left shore. Rather than attempt some estimate of average density across the entire river from insufficient data, Station C-306 was not included in the calculations.

As mentioned above, mixing was complete at Station C-278. Discharge rates cited in the survey report (1) indicated an average of 20 per cent dilution by the Snake River from September to May and one-third during the summer months.

Gross Beta Activities

Tables III and IV summarize gross beta activities in the Columbia River during two seasons: (a) September 1951 to May 1, 1952; September 1952 to March 1953, and (b) May 2 through August 1952. Comparison of Columns 5 and 8 in Table III, and Columns 4 and 7 in Table IV reveals that the

TABLE III.—Statistics on Radioactivity (Gross Beta $\times 10^{-8}$ μc/ml) Observed September 1 to May 1 (1951-1953) in Columbia River Survey, by Station

Station[a] (1)	Distances from Left Shore (ft) (2)	Number of Samples (3)	Mean Activity Density (4)	Standard Deviation of Density (5)	Coefficient of Variation (6) = (5)/(4)×100	Mean Log_{10} Activity (7)	Standard Deviation of Log Activity (8)
C-362	100,800,1000,1300,1600	161	797.5[b]	281.7	35.3	2.863[b]	0.155
C-339	100,500,1000,1500,1900	151	325.3	101.3	31.1	2.492	0.134
C-330	200,500,1000,1500,2000	149	243.8[c]	69.5[c]	28.5	2.369[c]	0.133
C-326	200,500,1500,2200	116	230.5[c]	74.0[c]	32.1	2.340[c]	0.147
C-316	400,1000,1500	78	185.7[c]	60.5[c]	32.6	2.248[c]	0.135
C-278	500,1000,1500	56	105.3[c,d]	35.3[c,d]	33.5	1.996[c,d]	0.163

[a] Number indicates miles from mouth of the Columbia River.
[b] Weighted as described in text.
[c] Adjusted for 5 per cent dilution by Yakima River.
[d] Adjusted for 20 per cent dilution by Snake River.

logarithmic transformation has largely stabilized the variation in activity, although more successfully in the winter season when the coefficient of variation showed greater constancy.

Uptake During Winter

Mean times of flow during September to May from Station C-362 to each of the downstream sampling points have been estimated from curves published in the report (1). They are based on a mean discharge rate of 80,000 cfs above the Snake River and 100,000 cfs below. Table V lists those times of flow together with observed differences in mean log_{10} activity between successive stations. Also included are theoretical differences, assuming no loss through uptake or deposition, obtained from Equation 9. For reasons given in earlier discussion the estimates used in this equation were based on hourly decay factors when applied to times of flow of less than 10 hr and 5-hr factors for longer flowtimes.

Judging from Table V, significant uptake of radioactivity occurred during the September to May seasons of the survey between Stations C-362 and C-330 but not farther downstream. Undoubtedly, some uptake did occur below these points since samples of plankton and algae taken at the other stations showed activity. (The Columbia River report (1) indicates that direct uptake of radioactivity from the

TABLE IV.—Statistics on Radioactivity (Gross Beta $\times 10^{-8}$ μc/ml) Observed May 2 to August 31 (1952) in Columbia River Survey, by Station

Station[a] (1)	Number of Samples (2)	Mean Activity Density (3)	Standard Deviation of Density (4)	Coefficient of Variation (5) = (4)/(3)×100	Mean Log_{10} Activity (6)	Standard Deviation of Log Activity (7)
C-362	70	315.9	165.2	52.3	2.421[b]	0.214
C-339	70	107.9	39.2	36.3	2.002	0.172
C-330	45	108.6[c]	40.9[c]	37.7	2.010[c]	0.152
C-326	48	96.6[c]	26.8[c]	27.8	1.970[c]	0.120
C-316	30	81.3[c,d]	32.7[c,d]	40.2	1.854[c,d]	0.266
C-278	15	46.1[c,e]	14.3[c,e]	31.0	1.640[c,e]	0.163

[a] Number indicates miles from mouth of the Columbia River.
[b] Weighted as described in text.
[c] Adjusted for 5 per cent dilution by Yakima River.
[d] Adjusted for 7 per cent dilution by Snake River.
[e] Adjusted for 33.33 per cent dilution by Snake River.

TABLE V.—Comparison of Observed and Theoretical* Differences in Mean Log_{10} Radioactivity Between Successive Stations on Columbia River, September 1 to May 1 (1951-1953)

Station	Mean Time of Flow from C-362 (hr)	Mean Log_{10} Activity†	Observed Difference in Mean Log_{10} Activity Between Successive Stations	Theoretical Difference from Equation 9
C-362	0	2.863		
			0.371 ± 0.016‡	0.239
C-339	7.5	2.492		
			0.123 ± 0.016	0.076
C-330	10.8	2.369		
			0.029 ± 0.018	0.035
C-326	12.5	2.340		
			0.092 ± 0.021	0.092
C-316	17.5	2.248		
			0.252 ± 0.026	0.260
C-278	35.5	1.996		

* Assuming no loss of radioactivity except through decay.
† From Table III, Column 7.
‡ Standard error of mean difference, based on numbers of observations and average standard deviation given in Table III, Columns (3) and (8), respectively.

water was due almost entirely to absorption by plankton and algae, bottom organisms and fish generally gaining their activity indirectly through the food chain.) Apparently, however, below Station C-330 such uptake was negligible relative to the density of activity in the water.

Each difference listed in Table V represents the ratio of a geometric mean concentration at one station to a similar mean at the next station downstream. Starting with an observed geometric mean activity of 730×10^{-8} $\mu c/ml$ at Station C-362, theoretical means at the other stations, assuming no loss except through decay, may be calculated and compared with observed values. For example, it may be shown that loss through uptake and deposition between Stations C-362 and C-339 amounted to an estimated 110

TABLE VI.—Comparison of Observed and Theoretical* Differences in Mean Log_{10} Radioactivity Between Successive Stations on Columbia River, May through August (1952)

Station	Mean Time of Flow from C-362 (hr)	Mean Log_{10} Activity†	Observed Difference in Mean Log_{10} Activity Between Successive Stations	Theoretical Difference from Equation 9
C-362	0	2.421		
			0.419 ± 0.030‡	0.185
C-339	5.1	2.002		
			−0.008 ± 0.034	0.060
C-330	7.8	2.010		
			0.040 ± 0.037	0.028
C-326	9.2	1.970		
			0.116 ± 0.042	0.061
C-316	12.0	1.854		
			0.214 ± 0.057	0.195
C-278	23.3	1.640		

* Assuming no loss of radioactivity except through decay.
† From Table IV, Column 6.
‡ Standard error of mean difference, based on numbers of observations and average standard deviation, given in Table IV, Columns (3) and (8), respectively.

$\times 10^{-8}$ μc/ml or 26 per cent of the entire reduction between these two stations.

Uptake During Summer

Similar calculations have been performed with respect to the observations of May to September 1952. Results are listed in Table VI. Average times of flow were again derived from the Columbia River report (1), based on discharge rates of 225,000 cfs above the Snake River and 350,000 cfs below. The former is a weighted average arrived at with the help of the report; the latter assumes an average contribution of 125,000 cfs from the Snake River during this season.

Again, the largest uptake of activity occurred between Stations C-362 and C-339, accounting, on the average, for 71×10^{-8} μc/ml, or 44 per cent of the total reduction in this area of the river.

Interestingly, the geometric mean density of activity in plankton and algae at Station C-339 during the high-flow, summer months was about one-fourth the density in fall and winter months (1). Tables V and VI, however, indicate an average uptake between C-362 and C-339 two-thirds (71/110) as great during the summer season. Presumably, this difference in results—one based on direct examination of plankton and algae, the other on inference from the water—was due simply to greater populations of these organisms in late spring and summer.

Obviously, good hydrographic data are essential to a meaningful application of the methods discussed here. The general importance of such data in stream surveys for radioactivity has been emphasized by Tsivoglou *et al.* (3).

Summary

Assuming a mixture of radionuclides emitted into a stream, the proportion of activity lost through uptake or deposition between two downstream sampling stations may be estimated by comparing observed activity densities at such points with those expected from natural decay alone. The latter are estimated from a mathematical model fitted to decay factors measured in water representative of the outfall. Selective uptake or deposition which alters the relative concentrations of the nuclides significantly may be detected by comparing initial average decay rates observed at downstream stations with average decay rates predicted for these stations from the model fitted to the outfall sample. Data from a survey of radioactivity in the Columbia River (1) during 1951–53 are used to illustrate the procedures.

References

1. Robeck, G. G., Henderson, C., and Palange, R. C., "Report of Water Quality Studies on the Columbia River." Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio (1954).
2. Cornell, R. G., "A New Estimation Procedure for Linear Combinations of Exponentials." Oak Ridge National Laboratory Report ORNL-2120, Oak Ridge, Tenn. (1956).
3. Tsivoglou, E. C., Harward, E. D., and Ingram, W. M., "Stream Surveys for Radioactive Waste Control." *Jour. Amer. Water Works Assn.*, 49, 6, 750 (June 1957).

THE OPERATOR'S CORNER

1958 OPERATORS' FORUM *

I. INTRODUCTION

By David P. Backmeyer, *Presiding Officer*

Superintendent, Sewage Treatment Plant, Miami, Fla.

In planning the Operators' Forum for this year, a special effort was made to select subjects which would be of particular interest to those of us actively engaged in plant operation. Letters were sent to 84 plant operators located in 27 different states requesting that two subjects not concerned with plant maintenance be listed as topics for discussion. The response was very gratifying. Replies containing 108 subjects for discussion were received from 54 operators.

Subject interest was centered in sludge digestion, sludge disposal, skimmings and scum removal and final disposal, sewage sampling, and treatment plant operator certification.

During the time allotted for the Forum, Hugh A. Schreiber, Superintendent, Washington, D. C., Sewage Treatment Plant, will lead the discussion on "Control of Digester Scum—Gas Circulation and Mechanical Mixing," and Roger D. Lee, Superintendent, Sewage Treatment Division, Wichita, Kans., will lead the discussion on the subject, "Grease and Skimmings Removal, Handling, and Disposal." Thomas T. Hay, Superintendent, Sewage Disposal Plant, Racine, Wis., will be the leader of the discussion on "Operator Certification." †

II. SCUM CONTROL AND HIGH-RATE DIGESTION AT THE DISTRICT OF COLUMBIA

By Hugh A. Schreiber

Superintendent, Sewage Treatment Plant, Washington, D. C.

In an effort to close the gap between available finances and municipal needs, a worthy goal is to make better use of existing facilities by developing higher degrees of control and more efficient methods of operation. Thus, capacities

* In part from the transcript, 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

† The panel discussion on certification begins on p. 607 of the May 1959 issue of This Journal.

may sometimes be increased without adding new structures.

One phase of sewage treatment that lends itself readily to this reasoning is the anaerobic digestion process. Proponents of sludge digestion consider this process a necessity for efficient, continuous, nuisance-free sewage treatment plant operation. Even the skeptic sees in sludge digestion an opportunity to, in some cases, increase plant capacity by the addition of a few refinements which may result in substantial savings both in time and money.

One purpose of this Forum is to discuss methods of increasing capacities of digesters without increasing their physical size. For this discussion superintendents and operators familiar with various types of equipment used to serve this end have been invited to discuss the merits of their respective systems. After a brief presentation dealing with four principal types of equipment, this Forum will be open to comments from the floor, at which time those interested may express their views as to the relative merits of or experience with the various systems.

As an introduction, a few comments on digester loading and the current and future plans for the Washington, D. C., plant may be appropriate. At the present time the plant is hampered by inadequate heating and excessive quantities of trash in the raw sludge. The plant expansion program now underway will result in the installation of equipment for four types of scum control and high-rate digestion processes in four different tanks together with the equipment needed in connection with the planned evaluation program. It is recognized that such an evaluation may require considerable time.

Before going into methods of increasing digester loadings, it may be well to review the conditions necessary for high-rate digestion. Influent sludge must be free of trash so that the digester contents can be maintained in an homogeneous state; there must be adequate heating capacity; and raw sludge must be of high solids content. The latter may be accomplished either by pumping thick sludge directly from the primary settling tanks, or in the case of secondary treatment, by having thickening tanks ahead of the digestion process. In addition, digested-sludge concentrating tanks must be provided unless the increased loading affords sufficient saving in digester volume so as to free some digester capacity for this work. This need arises because in high-rate digestion there is no supernatant and a means must be provided to concentrate the digested sludge in order to attain a sufficiently high solids content for efficient operation of vacuum filters or drying beds.

One method of reducing scum and increasing digester loading is by gas recirculation.* In this application, the gas developed by digestion is withdrawn from the digester, compressed, and discharged at an elevation below the liquid level in the digester. The number of discharge points and the distance below the liquid surface may vary considerably. In general, the submergence of the discharge pipes and the spacing of the pipes are such as to get practically complete disturbance of the surface of the tank. The released gas acts as a gas lift which causes turbulence on the surface to break up the scum accumulation and, at the same time, a more intimate mixing of the raw and partially digested sludge.

Some plants utilizing high-rate digestion have successfully used suspended solids loadings of 530 lb/day/1,000 cu ft of digester volume. For the District of Columbia the board of engineers has estimated permissible loadings at about one-half that amount.

* P.F.T.—Pearth System of the Pacific Flush Tank Co., Chicago, Ill.

III. SCUM CONTROL AND HIGH-RATE DIGESTION AT COLUMBUS, OHIO

By James H. Blodgett

Sewage Treatment Manager, Columbus, Ohio

Full-scale application of high-rate sludge digestion was begun in Columbus, Ohio, during May 1953 and has been in operation more or less continuously since then. This system employs gas recirculation * to accelerate digestion. The sludge being digested is a mixture of raw and excess activated sludge.

Solids loadings have averaged 300 lb/day/1,000 cu ft of tank volume. This loading is based on the total tank volume with no allowance for either digested-sludge storage or scum-occupied volume.

Except for short periods of shutdown to change gas diffusion elements and replace compressor parts, there have been few interruptions in the processing of sludge in the single digester equipped with this system.

It was originally intended, when the process was started, to activate the tank contents with recirculated gas during part of each day and then allow quiescent periods to separate the solids from the supernatant. It was found, however, that no such separation occurred and that a heavy scum quickly formed on the liquid surface during the quiescent periods. It also developed that the solids content of the digested sludge as removed was slightly lower than that of the raw sludge.

These conditions were due apparently to gas entrainment in the sludge particles. Resumption of gas recirculation very effectively eliminated the scum blanket, but the digested sludge's solids content still remained slightly below that of the raw sludge added.

It was concluded that the use of a secondary digester or concentration tank would result in a heavier digested sludge. The anticipated scum problem had to be taken into consideration so an adjacent tank was slightly modified for this purpose. In this tank the original raw sludge inlet pipe was connected to the suction side of a circulating pump located in the adjacent pipe gallery. In common therewith a connection was made to the digested-sludge drawoff line from the primary digester in which the accelerated process is operated. By means of a valving arrangement either digested sludge from the primary tank or intermediate liquor from the secondary may be admitted to the pump. The discharge from this pump is through a pipe located above the liquid level of the ing arrangement either digested sludge secondary tank. This pipe slopes downward at an angle of approximately 45° and is directed tangential to and roughly one-eighth of the tank diameter in from the tank wall.

The sludge pumped to the tank through this system imparts a measurable rotating motion to the top surface, thus moving the scum blanket under the sludge discharge pipe and effectively breaking it up. This scheme has been successful in reducing the thickness of a dry scum blanket from 4 or 5 ft to a foot or less in one 48-hr recirculation period.

The normal daily quantity of digested sludge transferred to the secondary tank is sufficient to keep the scum blanket under control for about a week; then it becomes necessary to operate the recirculation pump for a day or two to reduce the scum thickness to a satisfactory level.

There is no serious scum problem in

* Catalytic Reduction Process of the Chicago Pump Co., Chicago, Ill.

the primary tank because gas is recirculated continuously. Occasionally, 4 to 12 in. of scum forms next to the tank wall, the width of the blanket being about 5 or 6 ft. Analyses of the scum which forms in the secondary tank show that its solids content ranges from 30 to 50 per cent and that from 60 to 90 per cent of the solids are volatile.

Steps are now under way to construct a pilot plant to study ways of removing scum for direct incineration. Such a procedure would save the cost of conditioning and filtering scum as a liquid. Indications are that from 25 to 50 per cent of the solids from high-rate digestion can be disposed of by direct incineration and that sufficient heat can be recovered to eliminate the need for auxiliary fuel used in burning the balance of the solids.

IV. MECHANICAL MIXING OF DIGESTING SLUDGE AT ATLANTA, GEORGIA

By Van P. Enloe

Superintendent of Sewage Treatment Plant, Atlanta, Ga.

Mr. Paul J. Cerny made this penetrating statement in his article, "Sludge Digestion Can Be Improved," published in the October 1956 issue of *Civil Engineering*—"How frequently does a structure designed and equipped as a digester, turn out to be a combination unit providing immense storage capacity for scum, silt, dead sludge, and dirty water? Within this a small heart works frantically as a high rate digester. And does an excellent job."

Report after report gives us information on the reduction in size of grit collection equipment, sedimentation tanks, trickling filters, and other treatment units, yet sanitary engineers are calling for more capacity for heated separate sludge digestion units. Why?

Atlanta, in 1937, built four two-stage digesters at the R. M. Clayton Sewage Treatment Plant. These digesters, 90 ft in diameter, were designed for a total sludge capacity of 1.65 cu ft/cap, with 0.85 cu ft/cap provided in the two primary tanks. Their mixing and heating equipment consists of six turbine-type mixers and six heating coils equally spaced around the mid-section of the tanks.

Our experience with these digesters has been that a mound of silt, grit, and dead sludge builds up around the base bearings of the mixers to depths of from 6 to 8 ft. Rags and trash build up around the impellers and impeller shafts, overloading the driving motors and making the impeller blades ineffective in their operation. An area extending 10 to 12 ft inward from the walls also accumulates silt, grit, and dead sludge to depths of from 8 to 10 ft. A heavy scum layer forms on the surface but is apparently broken up in the area immediately adjacent to the mixers.

This leaves a "heart" of high-rate digestion—and it has been doing a pretty good job between times of dewatering for cleaning, renewing shaft bearings, and repairing heating lines.

The other plants in Atlanta have coil-heated digesters and are not equipped with stirring equipment. Nevertheless, they perform in a similar way, i.e., they show a buildup of silt and dead sludge on the bottom, a scum layer on the top, and a "heart" of high-rate digestion.

If these conditions are commonplace, why can't a digester be designed to be: (a) the size of the "heart"; (b) so shaped and mechanically activated that all settleable solids, silt, and grit will be kept in motion until removed; (c) properly heated to obtain good diges-

tion; and (d) able to keep scum formation at a minimum, with mixing equipment arranged to keep the remaining scum submerged and thus moving out with the digested sludge?

It is believed the use of newly designed, non-clogging mechanical stirrers, together with properly shaped digester bottoms, will result in much improved digester operation.

V. GAS RECIRCULATION AT AURORA, ILLINOIS

By Walter A. Sperry

Superintendent, Aurora Sanitary District, Aurora, Ill.

Aurora's contribution to this Forum is a brief report on a year's experience with a new approach to gas recirculation in digesters.

The gas recirculation equipment* used at Aurora consists of three gas-lift pumps located at the center of the digester. The lift tubes are 16 in. in diameter and 14 ft long. The upper ends of these tubes are welded into a circular discharge pan 3 ft 8 in. in diameter and 1 ft deep. This assembly is supported by an angle framework which is welded to the underside of the cover on the digester gas dome. The whole apparatus was lowered into the digester with a crane and without disturbing the digester contents. The apparatus was so positioned that the lip of the discharge pan is about 2.5 ft below the underside of the digester roof.

Gas is introduced to the lift tubes through three 2-in. stainless steel pipes. The lower end of each pipe is closed with a flat plate above which are four diffusion orifices. The orifices are sized so that each pipe will deliver 33 cfm at 5 psi. Each gas pipe enters the digester through a 6-in. tube which passes through the gas dome cover. The 6-in. tubes extend well below the tank liquid level to form a gas seal. This arrangement permits the 2-in. gas pipes to be withdrawn for inspection and cleaning.

Each lift tube has a capacity of 3,300 gpm. Thus 10,000 gpm of sludge can be circulated. The contents of the 40,000-cu ft digester are turned over about once every 30 min. The flow sweeps across the digester floor to the 16-in. draft tubes and then upward to the discharge pan.

The gas is compressed by a 250-cfm compressor powered by a 10-hp motor. The compressor output has been reduced to 100 cfm and the actual power requirement is 4.8 hp.

Results

In 1956 two identical 40,000-cu ft digesters were built at the Aurora plant. They are 50 ft square with a 16-ft side wall depth and the floors have a 1 on 6 slope to a central sump. The units have a flat-roof fixed cover. They are heated by an outside heat exchanger and are maintained at about 95°F.

Gas recirculation in Digester 1 began on Oct. 1, 1957. For the first three months of operation Digester 2 (not recirculated) was operated in parallel for comparative purposes. Average daily results for this three-month period are shown in Table I.

Beginning Jan. 1, 1958, recirculated Digester 1 was operated without reference to a control unit. Through Aug. 1958 it received nearly all of the primary sludge produced in an effort to evaluate performance under increased loadings. Between Jan. 1 and Sept. 1, 10 sampling runs were made. The results from these runs are summarized in Table II. Also shown in Table II are the results from four runs when

* Gaslifter unit of Walker Process Equipment, Inc., Aurora, Ill.

TABLE I.—Summary of Three-Months' Operating Results from a Recirculated and a Non-Recirculated Digester

Item	Digester 1 (recir.)	Digester 2 (non-recir.)
TS, raw sludge (%)	5.0	4.9
VS (as % of TS)	65.6	67.3
TS loading (lb/day/1,000 cu ft)	80.0	77.8
VS loading (lb/day/1,000 cu ft)	53.5	51.4
Gas produced (cu ft/lb of VS fed)	8.8	6.9
Gas produced (cu ft/lb of VS destroyed)	16.3	12.4
VS, transfer sludge (as % of TS, digested sludge)	48.4	47.4

TABLE II.—Summary of Operating Results under Increased Digester Loading

Item	Digester 1 (avg of 10 runs)	Digester 1 (avg of 4 runs*)
TS, raw sludge (%)	4.4	4.9
VS (as % of TS)	64.3	64.9
TS loading (lb/day/1,000 cu ft)	166	205
VS loading (lb/day/1,000 cu ft)	107	134
Gas produced (cu ft/lb of VS fed)	9.0	7.5
Gas produced (cu ft/lb of VS destroyed)	17.7	15.6
VS, transfer sludge (as % of TS, digested sludge)	44.7	47.7

* Four runs during which the loading was the highest.

the total solids loading was equal to or greater than 200 lb/day/1,000 cu ft. Additional operating data collected during the remainder of 1958 confirm the results reported for these four runs. For the 14-month period between Nov. 1957 and Jan. 1959 (the period of gas recirculation) over-all gas production was 8.8 cu ft/lb of VS added.

Numerous samples have been collected at various digester locations and the results show the contents to be well mixed except for a fillet of scum at the intersection of the roof and the side walls. The results of from 25 to 30 tests showed the total solids content to range from 3 to 7 per cent. The 7-per cent value applied to samples collected at the intersection of roof and wall; at all other points the solids content averaged between 3 and 4 per cent.

The settling quality of the transfer sludge seems excellent. The volatile content is below 50 per cent and the supernatant liquor is clear and free from settleable solids. About 50 per cent of the solids settle in 30 min leaving a clear supernatant of 0.16 per cent total solids and only 35 mg/l of suspended solids.

The increase in gas production in the recirculated digester is probably due to the intimate mixing of the digesting and raw sludge and to the further and important fact that the whole volume of the digester is brought into action. In digesters mixed intermittently by means of sludge recirculation pumps there is likely to be only a central "football-shaped" zone of activity. Much of the incoming sludge is held in inactive zones in the bottom, under the roof, and along the walls.

On July 1, 1958, the skimmings from the clarifiers were repiped to Digester 1, the recirculated unit. Formerly, this material was pumped to Digester 4 which is not recirculated. This older method of disposal had long been an intolerable nuisance, mostly due to the tendency of the skimmings to form heavy scum layers which at times made the addition of the daily accumulation almost impossible. This change in skimmings handling may prove to be the most important operational change made at Aurora in many years.

Floor Discussion

Clair N. Sawyer, Associate, Metcalf and Eddy, Boston, Mass.:—I would like to ask whether any of the members of the panel have experienced separation of grit in the primary digesters caused by gas recirculation, and if so, how this particular situation was handled? Then, I would also like to ask a question of Mr. Sperry regarding the supernatant liquor. I believe it was indicated that the volatile fraction of the transfer sludge was about the same

whether or not gas recirculation took place. I believe you also showed considerably lower gas production in terms of gas produced per pound of volatile matter destroyed in the unmixed digester. Now, if the volatile solids are destroyed they have to appear either in the form of gas or in the form of soluble material in the supernatant liquor which, of course, would suggest a much higher BOD for the supernatant from the unmixed digester. I was wondering if you have any information on the BOD of the supernatant from both the mixed and unmixed units?

Mr. Blodgett:—Well, I do not have any mounds of grit in my digester but we did have mounds of grit in the uncirculated digester. Strangely, we do not have any grit in the circulated unit. Of course, we have got a pretty good grit removal unit now.

Mr. Sperry:—I am sorry that that matter of the quantity of BOD in the supernatant liquor had not occurred to us. As I stated in my first remarks, the supernatant was of such excellent character that we passed over the matter of BOD. We will have to look into it.

Dr. Sawyer:—Thank you, Mr. Sperry. I think that an important point is involved here; one that may represent an important advantage of high-rate digestion that has not been brought into the picture. I have missed this point myself and I was hoping someone would be able to add information that is needed.

W. W. Mathews, Superintendent, Gary Sanitary District, Gary, Ind.:—What is the range of the per cent solids that you add to your digesters?

Mr. Blodgett:—Our raw sludge concentration is about 7 or 8 per cent. Digested sludge from the secondary tank runs around 8 or 9 per cent solids.

Mr. Mathews:—Do you attempt to carry say 5 or 6 per cent solids in the digesters or doesn't the concentration make any difference?

Mr. Blodgett:—It doesn't seem to make any difference. We take whatever we get; we try to get the sludge as heavy as possible.

Mr. Enloe:—We pump to our digesters from the primary clarifiers. We try to keep at least 4 per cent solids going to the digesters and we regulate our pumping schedule to accomplish this. As a rule we draw from the secondary digesters sludge having from 9 to 10 per cent solids.

T. R. Haseltine, Partner, Chester Engineers, Pittsburgh, Pa.:—If I understand Mr. Blodgett correctly, he has indicated that when he transfers sludge from his high-rate digester to the secondary tank some scum is formed and the cause has been attributed to gas entrainment. I'd like to ask Mr. Sperry, or any one else having experience with a gas recirculation system, if a similar scum-forming tendency in the transfer sludge has been observed?

Mr. Sperry:—No. In the two digesters we use as secondaries we've had no particular problem and we get sludge to the sand drying beds with up around 8 or 9 per cent solids. But as I stated earlier the settling quality of our transfer sludge has been most satisfactory. We feel that it could have been run directly to the sand beds had we elected to do this.

Mr. Blodgett:—Perhaps, Mr. Sperry, in transferring from one tank to another sufficient gas is released so that you do not form scum similar to that which collects on the surface of the one tank we use for concentrating.

Mr. Sperry:—This may be somewhat irrelevant, but after Mr. Blodgett's remarks about releasing gas, I think I had better tell you about a unique situation we have at our plant. When we built these two new digesters I finally was able to get what I had long wanted. Now when we transfer sludge from the three primary digesters the

sludge goes first to an intermediate tank. From there it is pumped to the secondary tank. This, of course, provides an opportunity for gas release. The two pumps used to transfer sludge are controlled automatically by compressed-air equipment so that the pumping of transfer sludge to the intermediate tank and the pumping of the primary sludge go on almost simultaneously. Shortly after raw sludge pumping has been finished, sludge from the intermediate tank is passed through one of the sludge meters and sent to the secondary. In this way it is possible to sample and measure the flow of the transfer sludge.

Earl R. Howard, Executive Engineer, Metropolitan District Bureau of Public Works, Hartford, Conn.:—I would like to put in a plug for gas recirculation. At the Hartford plant there are four fixed-cover digesters, all designed for primary operation. Over the years we got into a situation where we were carrying anywhere from 8 to 9 ft of scum in these tanks and it began to look as though we were going to have to add digester capacity. Then we decided to try gas recirculation and got our plant in good enough shape to start a trial run. We greatly reduced the scum thickness in a period of a week or so.

We have now equipped two of the four digesters with gas recirculation equipment. We are not equipped for a good primary-secondary transfer operation; however, we have been able to get the overflow from the two primaries into the other two tanks and we now are using two-stage digestion. We do have a little bit of scum appearing in the secondary, and just how we are going to get it under control I don't know. With gas recirculation we might be able to continue in Hartford without having to build additional digesters; we may have to build a sludge thickening tank, however. We find our heat transfer is much improved by gas recirculation.

VI. REMOVAL AND DISPOSAL OF GREASE AND SKIMMINGS AT WICHITA, KANSAS

By Roger D. Lee

Superintendent, Sewage Treatment Division, Wichita, Kans.

Wichita is a city of 250,000 located in south-central Kansas. It is a major trade center for a large area, consisting of portions of Kansas, Oklahoma, Texas, and Colorado. Important industries located there are aircraft manufacture, milling, meat packing, and oil refining.

Wichita is served by separate sanitary and storm sewer systems. Efforts, on the part of state and local health departments, to eliminate pollution of small watercourses within and flowing through the city have been successful in that most polluted waters are now being discharged to the sanitary sewers. The number of sewer connections is estimated to be approximately 68,000. It is also estimated that about 20,000 household garbage grinders have been installed. Ground garbage from this segment of the population and wastes from the meat packing industry have created problems in the handling of grease and skimmings.

Handling Skimmings

The Wichita primary treatment plant includes mechanically cleaned bar screens (with the screenings ground and returned to the flow), grit removal facilities, preaeration tanks, settling basins, and two-stage heated digesters. Skimmings consist of grease, other usual materials, and some paunch manure. The first removal of grease

occurs in the preaeration tanks. The average detention time is 1.8 hr at 25 mgd with air supplied at about 0.17 cu ft/gal of sewage. Grease accumulates on the surface in the form of grease balls which are removed as necessary—usually about once every three months. Grease balls have been removed manually in the past.

Tractor Use

Early in 1958, a tractor with a ½ cu yd front-end bucket was purchased for use in sludge handling. This equipment has so far been used only once to remove grease balls from the preaeration tanks. The tractor was driven to the edge of the basin and the bucket lowered over the rail. To submerge the bucket it was necessary to close partially the gates at the tank outlet and thus raise the liquid level. Manipulation of the air and some steering, using paddles, enabled the operators to get the grease balls into the bucket. When the bucket was raised and the sewage flowed out of the bucket, however, the grease balls were carried out too. It was necessary eventually to lower the bucket to just above liquid level and then flip the grease balls into it. Some of the balls weighed about 15 lb and the work involved was considerable. Approximately 8 cu yd (1½ truck loads) of grease balls were removed. Eight man-hours were required for this work. They were then hauled to the grit disposal area on the river bank and buried. Purchase of a detachable, perforated bucket to mount under the regular equipment bucket is planned and it is believed its use will materially reduce the man-hours required to remove grease balls from the tanks.

Three months may seem to be too long a period to leave grease balls in the preaeration tank. Anaerobic decomposition of the grease and entrapped sewage solids must occur with the consequent production of odorous gases. As nearly as can be determined, however, the odors produced have no effect at the plant. The Wichita sewer system is laid on flat grades and considerable deterioration of the sewage occurs in the sewers. As a result, there is a release of sulfides and other odorous gases in the flume receiving the lift-pump discharge and in the preaeration tanks. There is little, if any, difference in the intensity of the odor at this end of the plant after the grease balls have been removed.

Skimming Trough Use

Grease and skimmings which are not removed in the preaeration tanks are removed in the settling basins. The plant has two rectangular basins, each subdivided into three sections. These were built in 1932 but modified and improved in 1955. Skimmings are removed by a skimming trough located ahead of the weirs. These basins, designated as No. 1 and No. 2, are equipped with collecting and skimming mechanisms. There are also two circular basins, designated as No. 3 and No. 4, which were constructed in 1955. These too are equipped with sludge collecting and skimming mechanisms and each has a 4,000 gal scum pit. Skimmings from basins Nos. 1, 2, and 3 are drawn to pit No. 3 and skimmings from basin No. 4 are drawn to pit No. 4. The excess water drawn to the pits with the skimmings is pumped back to the settling basins. Sludge is drawn from basin No. 3 or basin No. 4 into the pit and mixed with the skimmings by using compressed air. The skimmings-sludge mixture is then pumped to the digesters through the sludge lines. Approximately 30 cu ft of grease and skimmings (30 per cent of which is grease), mixed with 4,000 gal of 5-per cent sludge, are pumped each day.

Effect of Grease on Digestion and Digester Equipment

One of the three primary digesters was cleaned during the summer of 1958

and gas recirculation equipment was installed at that time. Although the cleaning operation revealed a thick scum layer which contained paunch manure, animal hair, and straw, there was no indication that grease had failed to digest or had affected the quality of the sludge. By using gas recirculation to keep scum-forming materials dispersed through the active digestion zone (or by extending the zone of active digestion upward to the cover) the portion of the digestible grease and skimmings that would otherwise be present in the scum layer should be digested. Since the practice of pumping the grease and skimmings to the digester did not hinder digestion prior to the installation of the gas recirculation system, no adverse effect on the digesters or the digestion process is anticipated as a result of the installation of the new equipment.

The digester heating system uses external heat exchangers and there is no indication that grease and skimmings reduce line capacity in the heater recirculation system. Continuous recirculation of heated digester liquor apparently eliminates the buildup of grease in the lines. Locating plant units in such a way as to reduce the length of the pump-discharge line necessary to tie into the recirculation system may be indicated by this experience.

Other Methods of Grease Disposal

Two firms which specialize in the collection of inedible greases from sewage treatment plants have inquired into the possibility of obtaining grease from Wichita. One firm desired to obtain at least 12,000 lb each time it collected, which would have necessitated installation of storage facilities. The other firm proposed to collect daily. Grease and skimmings handling at Wichita is so little trouble and so inexpensive, however, that neither proposal was attractive.

Sludge Line Cleaning

The maximum sludge pumping rate is 175 gpm through a clean line. The grease in the skimmings adheres to the line, particularly at the Venturi tube, and a gradual reduction in the pumping rate is observed.

Two types of remedial action are practiced. Plant attendants back-flush the line weekly, using about 25,000 gal of warm supernatant from the digesters. Since early 1958, experimental treatment with caustic has also been tried. This method consists of pumping 200 lb of flake caustic, dissolved in water, into about 450 ft of 6-in. line. The concentration is approximately 0.3 lb/gal. The solution is left in the line for approximately 12 hr and is then back-flushed, using warm supernatant, into about 100,000 gal of sewage. Pump discharge rates for sludge increased from 100 gpm to 175 gpm over a period of several days following this treatment. Prior to use of the caustic treatments it was necessary to remove the Venturi tube and rod the line at intervals ranging from two to eight months. While it is not likely that caustic treatment will completely eliminate the necessity for rodding, its use appears to reduce the need substantially. Rodding requires approximately three and a half man-days and costs approximately $60 each time it is required, or a total of about $120 per year. The caustic treatment requires approximately two man-hours of time (at a cost of $4) and 200 lb of caustic (at a cost of $15) for a predicted annual cost of $80. These figures do not imply that caustic treatment is the best answer to the problem of cleaning the line or that it will replace rodding. To date no attempt has been made to establish how the caustic acts in restoring line capacity. It is possible that continued use of the treatment may reveal objections not now apparent.

VII. REMOVAL AND DISPOSAL OF GREASE AND SKIMMINGS AT MINNEAPOLIS–SAINT PAUL, MINNESOTA

By Kerwin L. Mick

Chief Engineer and Superintendent, Minneapolis-Saint Paul Sanitary District, Saint Paul, Minn.

In the fine discussion of grease and skimmings disposal at the Wichita plant mention was made of the formation of grease balls on the preaeration tanks which occasionally reach a weight of 15 lb. At Minneapolis-St. Paul, grease balls have formed on the air flocculators but they have not reached anywhere near the size reported for Wichita. They are skimmed off by hand periodically.

Also described for Wichita were the methods used for cleaning sludge lines by flushing with warm supernatant, with caustic solution, and by rodding. At Minneapolis-St. Paul we have had even more difficulty with these grease deposits in our sludge lines. Mr. Sager described our experience with this problem on the Plant Maintenance panel yesterday morning.* We soon abandoned cleaning these lines with a cable and knife machine in favor of a hydraulically operated scraper. In order to use this, we had to remove the Venturi meters from the sludge lines but considered it no great loss because we could not keep them operating accurately. We now use a liquid-level recorder in our sludge concentration tanks to measure raw sludge volumes.

Scum Lagoon

At Wichita the grease and skimmings are pumped with the sludge to the digesters and have apparently caused no great difficulty there, contrary to experience in some other plants. At Minneapolis-St. Paul there are no digesters. The skimmings are flushed to an air ejector and blown through a 4-in. pipe to a scum lagoon. The scum lagoon is ignited once or twice a year. A second lagoon receives the skimmings while the first one is burning. This is a very economical and simple method of final disposal for the skimmings but it does create temporary smoke and odor nuisances. When the lagoon is first ignited the smoke and flames sometimes rise 200 or 300 ft into the air for short periods. Then the lagoon will smolder and occasionally flare up. The possibility of controlled incineration of the skimmings either in a regular sludge incinerator such as is done here in Detroit or in a specially designed separate incinerator is being studied.

Some data on the characteristics of the settling tank skimmings from Minneapolis-St. Paul may be of interest. On a dry basis, they are about 98 per cent combustible and have a fuel value of about 13,000 Btu/lb. The skimmings contain approximately 78 per cent animal and vegetable fats and 10 per cent mineral oils.

Some experimentation has been done on pumping this material. In the first year of operation at this plant ordinary centrifugal pumps were used. These were unsatisfactory and air ejectors were installed. This year a rotary pump called a "Bump" pump has been tried. This unit is especially designed for very heavy viscous materials containing large solids or semi-solids. This pump appears to successfully handle the heavy scum after it has been decanted and is ready for incineration.

Incineration

Several types of incinerators might be used for burning skimmings. A few years ago, the author saw a very clever one at the Peoria, Ill., plant.

* This discussion appeared on p. 485 of the April 1959 issue of This Journal.

Here, the operators had constructed a small oil-fired incinerator directly on the circular settling tank to burn the scum as it was removed by the skimming mechanism.

An incinerator company has experimented with burning the Minneapolis-St. Paul scum and has submitted a proposed design for an inclined hearth incinerator.

At Detroit, the scum is decanted and pumped through a motor-operated control valve directly to a multiple-hearth sludge incinerator. At Minneapolis-St. Paul, however, burning this high-volatile scum might appreciably reduce incinerator capacity for sludge cake. The volatile content of the filter cake burned at Detroit averages only about 52 to 54 per cent while the filter cake at Minneapolis-St. Paul contains about 72 per cent volatile matter. Detroit also burns its low-volatile grit in the same incinerators.

The Sanitary District of Chicago has been experimenting since 1955 with a 2-ft diameter, model incinerator designed by its own staff to burn the scum as it floats on a water surface. The scum is introduced below the surface of the water and floats to the top where it is burned. The combustion products are removed through a stack and the ash settles to the bottom of the water chamber and can be drawn off periodically with the water. The design incineration rate is about 0.4 cu ft/hr/sq ft of liquid surface. In the model tests, combustion at the liquid surface gave a clean, orange-colored flame with practically no smoke or odor. It is understood that a full-scale scum incinerator operating on this principle is to be built.

VIII. REMOVAL AND DISPOSAL OF GREASE AND SKIMMINGS AT HAMPTON ROADS, VIRGINIA

By Frank H. Miller

General Manager-Chief Engineer, Hampton Roads Sanitation District Commission, Norfolk, Va.

The Sewage Treatment Division of Wichita is to be commended on having sought an original approach to the very difficult problem of grease disposal by mechanical means. The Division is also to be congratulated on its good fortune in having, at its plant, climatic conditions or sewage characteristics which permit the holding of grease for as long as three months. Many operators, however, are not so favored.

Handling Skimmings

At Hampton Roads several attempts have been made to mechanize the removal of accumulated grease, but by a different method than that employed at Wichita. Invariably, however, these efforts have been impeded by the (a) near impossibility of draining off the water from the collected grease; (b) the unfortunate characteristic of the material which results in its sticking to and/or clogging anything with which it comes in contact; and (c) the difficulty encountered in trying to get the material to flow by any orderly pattern to a central point of collection.

In the report of the Wichita operation, reference was made to the formation of 15-lb grease balls. Since balls of comparable size accumulate in the 35 pumping station wet wells which the Commission operates in the Hampton Roads area, it would be interesting to know if these grease balls originate upline or in the preaeration facilities.

The difficulty of reaching positive conclusions with respect to matters affecting digester operation is well recognized. Nevertheless the conviction has been held at Hampton Roads for several years that the discharge of skimmings and grease into the digesters re-

sulted in the formation of a scum layer, or at least materially increased this layer.

Tests of scum layers, which at times were 6 to 8 ft deep, showed the grease content to be more than 20 per cent. It was therefore considered necessary to eliminate direct skimmings loadings to all eight digesters which are operated by the Commission. It is believed that this action reserved digester capacity for more necessary purposes and did not add materially to the problem of scum handling. While this procedure did make it necessary to dip the skimmings into G. I. cans for subsequent burial or incineration at a nearby city incinerator, this was more than offset by the advantages of having less difficulty in keeping sludge lines open and a substantial reduction of digester problems. Many other variables, of course, come into the question of the extent to which digester problems were reduced. But unquestionably less difficulty was experienced with scum and with the maintenance of digester capacity than was the case when this capacity was used to accommodate the grease load from the primary clarifiers.

It should be noted that gas recirculation is probably very pertinent to the effect which grease has on digesters. At this time, however, no information is available at Hampton Roads to either confirm or deny this contention. It might also be interesting to note that grease accumulation does occur, to a fairly heavy degree, in the 6-in. raw sludge lines at Hampton Roads, even though a very conscientious effort was made to prevent skimmings from entering these lines. These coatings must therefore be attributed to the grease content of the raw sludge. At Hampton Roads the raw sludge lines usually require cleaning at approximately annual intervals. This is done by power-driven augers since these have been found to be the only really successful means of getting through the buildup.

Effect on Receiving Waters

The problem of handling grease is one of the most difficult, thankless, and noxious jobs encountered in sewage treatment plant operation. For this reason it is one that is evaded by operating personnel at any time an opportunity for such evasion exists. At Hampton Roads a primary effluent is discharged to tidal waters where the BOD is substantially no problem and where solids loading is not a serious problem. The main objectives are the reduction of bacteria and the removal of those fouling and unsightly components of the sewage flow. Failure of standard skimming devices to remove accumulated grease adequately, possibly compounded to some degree by an operator's understandable tendency to work the skimmings under the "splitlog," has resulted in problems at (and downwind of) the effluent discharge point. At times this has been a problem of considerable proportions. One of the most valuable and beautiful residential waterfronts on the East Coast is located about a mile downwind from the effluent discharge point of one of the three treatment plants in the area. Small grease particles appear to become mixed with floating seaweed and other organic material and result at times in a very serious odor problem along this shore.

Equipment Improvements Needed

It is believed that present grease-removal devices could be materially improved and that this would benefit both primary plants and secondary plants. If a continuous removal of skimmings from settling basins could be accomplished and, following this, if specific grease-separation facilities could be provided which could take the decanted liquid off the grease and, in effect concentrate and clean the grease, the operation would be very much improved. Such facilities would probably operate on the principle of continuous skim-

ming and decanting, rather than on the present intermittent and largely manual method.

This subject is an important one and deserves its place on the agenda of this meeting of the Federation. It is to be hoped that it will remain the subject of sufficient consideration until a more adequate solution to it is forthcoming —hopefully in the very near future. In this endeavor the consideration of the equipment manufacturers is earnestly besought as it appears likely that the successful solution to the problem will involve new methods, new procedures, and new equipment.

Floor Discussion

Joseph B. Hanlon, Superintendent, Sewage Treatment, Metropolitan District Commission, Boston, Mass.:— These grease balls, aren't they formed in the aeration tanks?

Mr. Lee:—Yes, sir.

Mr. Hanlon:—The reason I asked this question is that whenever we have a defective aeration unit, a slow rotary motion is set up in that area, and we seem to be able to roll up 15-lb grease balls in a very short time. But after the tube is fixed, the grease balls break up and are captured in the skimming area. I am wondering if a ball of the size you mentioned could get through the screens or whatever you may have ahead of the aeration tank.

Mr. Lee:—Well, I don't believe the grease balls come through the bar screens. These 15-lb grease balls are the exception. I probably gave the wrong impression. Most of the grease balls are smaller. They are about the size of an orange, but we also have some of the large ones. It usually takes two or three months for them to form. They are not formed in a period of just a couple of days in the preaeration tanks.

John C. Funk, Chief Operator, Sewage Treatment Plant, Ashtabula, Ohio: —I am right in the middle of trying to solve this grease problem and I hope I am going along the right lines. What I have done is to skim grease from the primary clarifier and recirculate it to the preaeration tank in order to form balls which are easy to handle. These are then skimmed off. We have on order a small incinerator and we plan to burn both the screenings from the bar rack and the grease.

If anybody else has tried this, I would like to hear about it.

From the Floor:—I hope this incinerator is big enough and adequately constructed to tolerate the high Btu content of the grease balls.

Mr. Schreiber:—Mr. Lee, I would like to come back to cleaning raw sludge lines with caustic. What is the temperature of the water that you use? What type of caustic do you use? Do you pump the spent solution to your sedimentation tanks or do you put it into your digesters?

Mr. Lee:—The temperature is around 60°F. It is our plant tap water and it is taken from our own well. The caustic we use is just plain commercial flake caustic that we buy from the local chemical supply houses. We back-flush the caustic into the sedimentation basins.

I think the discussion this morning has clearly indicated that the problems in handling grease and skimmings are complex and varied. None of us has come up with the final answer, but some workable schemes have been described. By next year some of you will probably have answers to current problems. These answers will be welcome words to most of us.

DEEDS AND DATA

"Not failure, but low aim, is crime."—Robert Browning

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Highlights from the Annual Reports of Alexandria, Va., Boise, Idaho, Buffalo, N. Y., Cranston, R. I., Defiance, Ohio, De Kalb, Ill., Detroit, Mich., East Bay Municipal Utility District, Oakland, Calif., Fond du Lac, Wis., Fort Wayne, Ind., Gary, Ind., Grand Rapids, Mich., Jackson, Mich., Kenosha, Wis., Menlo Park, Calif., New Rochelle, N. Y., Oshkosh, Wis., Painesville, Ohio, Santa Rosa, Calif., Walla Walla, Wash., Washington Court House, Ohio, and Washington, D. C.

SAMUEL W. SHAFER, *Engineer-Director, Alexandria, Va., Sanitation Authority;* A. J. WAHL, *Superintendent, Boise, Idaho;* FREDERICK W. CRANE, *General Manager, Buffalo, N. Y., Sewer Authority;* WALTER C. ANDERSON, *Superintendent, Cranston, R. I.;* DONALD E. HAZELSWART, *Superintendent, Defiance, Ohio;* DONALD E. HENN, *Engineer-Manager, De Kalb, Ill., Sanitary District;* FRED H. BURLEY, *Engineer of Sewage Treatment, Detroit, Mich.;* ELMER E. ROSS, *Manager, Sewage Disposal Division, East Bay Municipal Utility District, Oakland, Calif.;* CLARENCE W. BOGENHAGEN, *Superintendent, Fond du Lac, Wis.;* PAUL L. BRUNNER, *Superintendent, Fort Wayne, Ind.;* W. W. MATHEWS, *Superintendent, Gary, Ind.;* HUNTLEY DELANO, *Superintendent, Grand Rapids, Mich.;* R. A. GREENE, *Superintendent, Jackson, Mich.;* FRANK I. VILEN, *Superintendent, Kenosha, Wis.;* CEDRIC WEBSTER, *District Manager, Menlo Park, Calif., Sanitary District;* JAMES M. BROWN, *Superintendent, New Rochelle, N. Y., District Sewage Treatment Plant;* R. W. FRAZIER, *Engineer-Superintendent, Oshkosh, Wis.;* JOHN R. WOLFS, *Supervisor, Painesville, Ohio;* M. B. MCKINNIE, *Superintendent, Santa Rosa, Calif.;* C. S. ZICKEFOOSE, *Superintendent, Walla Walla, Wash.;* C. J. MARKHAM, *Superintendent, Washington Court House, Ohio;* and HUGH A. SCHREIBER, *Superintendent, Washington, D. C.*

Activated Sludge

A mass of floating sludge that has been appearing in the secondary settling tanks in Boise, Idaho, during cold weather has been eliminated by recirculation. From December to March during the hours from 7 PM to 7 AM effluent from the secondary launder is returned to the head of the plant. This procedure has increased the DO in the raw sewage and shortened the overnight detention in the treatment units.

At Jackson, Mich., the following procedure is used for cleaning diffuser plates: One tank at a time is dewatered, then water is hosed on the plates until the plate holders are full of water. Concentrated chromic acid is then brushed on the plates and is allowed to remain for about 15 min. The air supply is then turned on and additional water is hosed on the plates to prevent injury to the aluminum plate holders. This method is believed to do less damage to the plate holders than

cleaning methods which require removal of the plates. Before cleaning, pressure on the discharge side of the blower was 8 lb 4 oz; after cleaning the pressure was 6 lb 8 oz, almost as low as when the plates were new.

One of the two aeration tanks at Cranston, R. I., has been modified to permit step aeration. Settled sewage is added at four points along the length of the tank. Results to date indicate that step aeration will permit greater quantities of sewage to be treated; BOD loadings of up to nearly 60 lb/1000 cu ft have been applied.

Effluent Utilization

During the period from mid-June to mid-October all treated sewage from the Walla Walla, Wash., treatment plant is used for irrigation. Two irrigation districts compete for the effluent.

Industrial Wastes

Over the 3-yr period 1956–58, tannery wastes treated at the Fond du Lac, Wis., trickling filter plant have had an average BOD population equivalent of approximately 25,000, while the population equivalent of the domestic wastes was about 42,000. Thus about 37 per cent of the total wasteload treated comes from the tannery.

Tannery wastes were also in the picture at the Santa Rosa, Calif., treatment plant. Here, the fire department indicated that vats at an old tannery were so great a hazard that emptying would be necessary. Pumping the 240,000 gal of waste to the sewer took 3½ days. Unfortunately, even this relatively slow discharge to the sewers did not prevent the waste from killing the growth on the trickling filter. Ponding followed but high-pressure hosing relieved this undesirable condition.

The quantity of textile wastes discharged to the Cranston, R. I., treatment plant increased by more than 50 per cent during the year and constituted 13 per cent of the total city waste flow. Possibly as a result of this increase, BOD and suspended solids removals in the primary sedimentation dropped to 9 and 27 per cent, respectively. Normally, about 40 per cent of the BOD and 60 per cent of the suspended solids are removed.

Metering

During winter months, condensation in the unheated metering stations on the Alexandria, Va., sewerage system causes recurrent failures of the mechanisms. The problem was solved by placing perforated cannisters of silica gel in the meter cabinets. Cannisters are exchanged weekly. The saturated ones are processed for reuse by baking in an oven.

Operation

Operating data from 21 treatment plants appear in Tables I, II, and III. Data in Table I are from activated sludge plants; data in Table II from trickling filter plants; and data in Table III from primary plants. A total of 32 years of operation are represented in these three tables.

Personnel

After nine years of operation the Boise plant reports that no time has been lost by any employee because of an on-the-job accident. The Boise plant reports further that 12 former operators now hold the position of superintendent or foreman in other municipal treatment plants in the Pacific Northwest.

Sedimentation

Some measure of the life of sludge collecting mechanisms can be appreciated by the fact that after 28 years of service both the primary and secondary clarifier collectors at De Kalb, Ill., were reconditioned and placed back in service.

Sewers

Power rodding of sewers in the Menlo Park Sanitary District, Menlo

TABLE I.—Operating Results from Six Activated Sludge Plants

Treatment Plant	Operating Yr Ending	Est. Pop. Served	Sewage Volume				Sewage Temp. (°F)			Sewage Strength (mg/l)				Efficiency of Treatment (%)						Grit Removed (cu ft/mil gal)
			Avg (mgd)	Max Day (mgd)	Min Day (mgd)	Per Cap (gpd)	Avg	Max	Min	Influent		Effluent		Primary Unit		Secondary Unit		Over-all		
										BOD	SS	BOD	SS	BOD	SS	BOD	SS	BOD	SS	
1. Boise, Idaho	12/58	29,700	6.6	—	—	223	—	—	—	98	160	5	9	33	49	92	89	95	94	—
2. Cranston, R. I.	9/58	42,714	4.2	6.2	2.5	99	—	—	—	206	169	26	28	9	27	86	77	87	83	1.7
3.	9/57	41,814	3.6	5.2	2.4	87	55	—	—	261	182	25	28	21	37	88	75	90	85	2.2
4.	9/56	39,753	4.2	5.8	1.9	105	52	—	—	236	163	28	28	18	37	85	73	88	83	1.7
5. Fort Wayne, Ind.	12/57	142,000	23.	50.	13.5	162	—	—	—	175	237	15	22	—	—	—	—	92	90	2.4
6. Gary, Ind.	12/57	147,500	28.	—	—	189	60	—	—	220	379	19	18	58	65	79	86	91	95	4.8
7. Grand Rapids, Mich.*	6/58	196,850	35.	—	—	176	59	—	—	113	150	19	45	25	28	75	58	78	68	0.8
8. Jackson, Mich.	6/58	50,000	10.	—	—	200	—	—	—	119	186	9	9	20	12	91	94	93	95	0.8

Treatment Plant	Primary Sedimentation				Activated Sludge								Disinfection	
	Surface Overflow Rate (gpd/sq ft)	Raw Sludge			BOD Loading (lb/day/1,000 cu ft)	Air Use (cu ft/lb of BOD removed)	Air Use (cu ft/gal of sewage)	Aeration Period (hr)	Return Sludge (%)	Mixed Liquor		Sludge Index	Cl_2 Dosage (mg/l)	Effluent Quality (MPN/ml)
		Volume (cu ft/mil gal of sewage)	Dry Solids (lb/mil gal of sewage)	Solids Conc. (%)						DO (mg/l)	SS (mg/l)			
1. Boise, Idaho	—	910	—	—	—	1,730	0.91	—	27	2.3	1,071	—	1.4	—
2. Cranston, R. I.	844	962	2,950	4.9	—	1,675	1.83	5.5	43	4.4	1,328	0.75	4.0	—
3.	726	1,077	2,890	4.3	31	1,320	1.77	5.4	56	4.7	1,768	0.75	3.7	—
4.	833	636	1,715	4.3	33	1,066	1.36	5.9	36	5.0	1,820	0.65	3.0	—
5. Fort Wayne, Ind.	—	678	1,900	4.5	30	603	0.79	6.2	31	3.2	3,174	1.35	—	—
6. Gary, Ind.	—	630	2,025	5.2	20	820	0.49	5.1	36	2.6	3,031	0.89	—	—
7. Grand Rapids, Mich.*	—	425	1,501	4.6	—	1,166	0.57	3.4	20	4.7	511	0.34	—	—†
8. Jackson, Mich.	—	515	1,450	4.5	22	765	0.56	5.2	23	—	2,300	2.9	—	—

Treatment Plant	Sludge Digestion												Sludge Filtration				Operating Cost ($/mil gal)
	VS Loading (lb/day/1,000 cu ft)	VS Red. (%)	Temp. (°F)	Vol. Acids (mg/l)	Alk. (mg/l)	pH	Supernatant		Gas				Dry Yield (psf/hr)	$FeCl_3$ Fed (%)	$Ca(OH)_2$ Fed (%)	TS in Cake (%)	
							Volume (cu ft/mil gal of sewage)	Solids Conc. (mg/l)	Produced (cu ft/day/cap)	Produced (cu ft/lb VS fed)	Used (%)	Heat Value (Btu/cu ft)	CO_2 (%)					
1. Boise, Idaho	—	—	93	—	—	6.9‡	—	—	—	—	—	—	—§	—	—	—	23.56
2. Cranston, R. I.	—	—	—	—	1,925	6.9	—	22,000	1.32	—	57	—	—	3.3	6.3	0	17	63.19
3.	—	—	—	—	2,315	6.9	—	20,000	1.29	—	63	—	—	3.2	7.5	0	17	84.23
4.	—	—	—	—	2,208	6.9	—	19,000	1.45	—	58	—	—	3.3	6.3	0	19	55.19
5. Fort Wayne, Ind.	—	53	—	—	—	7.2‡	360	2,500	1.10	6.8	88	—	—	—¶	—	—	—	22.94
6. Gary, Ind.	67	—	90–100	—	—	6.9	—	—	1.08	3.8	—	590	29	—§	—	—	—	19.51
7. Grand Rapids, Mich.*	74	51	—	—	—	7.4‡	408	14,500	1.13	6.4	—	615	39	—	—	—	—	23.25
8. Jackson, Mich.	—	49	85	—	—	7.1	330	839	0.99	6.0	84	—	32	—¶	—	—	—	27.60

* High-rate activated sludge. † Ranges from 17 to 34,000 during months chlorine is added. ‡ Supernatant. § Drying beds used. ¶ Drying beds and lagoons used.

TABLE II.—Operating Results from Six Trickling Filter Plants

Treatment Plant	Operating Yr Ending	Est. Pop. Served	Sewage Volume				Sewage Temp. (°F)			Sewage Strength (mg/l)				Efficiency of Treatment (%)						Grit Removed (cu ft/mil gal)
			Avg (mgd)	Max Day (mgd)	Min Day (mgd)	Per Cap (gpd)	Avg	Max	Min	Influent		Effluent		Primary Unit		Secondary Unit		Over-all		
										BOD	SS	BOD	SS	BOD	SS	BOD	SS	BOD	SS	
1. Alexandria, Va.[a]	9/58	105,700	10.	—	—	95	—	—	—	222	227	43	42	—	—	—	—	79	79	2.9
2. De Kalb, Ill.[a]	12/58	—	1.9	—	—	—	—	—	—	187	250	13	21	29	62	91	75	94	91	—
3.	12/57	—	—	—	—	—	—			construction work in progress								—	—	—
4. ↓ [b]	12/56	15,500	1.2	2.3	1.0	77	60	—	—	175	196	39	37	30	56	68	57	78	80	—
5. Fond du Lac, Wis.[b]	12/58	32,000	3.8	7.5	0.6	119	62	74	42	386	401	113	24	—	—	—	—	71	92	5.5
6.	12/57	31,500	3.7	10.2	1.3	117	62	72	47	372	446	114	46	—	—	—	—	70	90	6.5
7. ↓	12/56	31,500	4.0	11.3	1.4	127	60	72	42	335	569	86	45	—	—	—	—	74	92	6.7
8. Santa Rosa, Calif.[c]	6/58	21,000[d]	6.0	17.	2.7	—	—	—	—	195	217	9	44	39	63	65[e]	45	95	80	0.5
9. Walla Walla, Wash.[f]	4/58	24,102[d]	6.5	7.7	5.7	—	—	—	—	93	109	12	21	23	55	83	57	87	81	—
10. Walla Walla, Wash.[f]	4/57	24,102[d]	6.3	7.2	5.6	—	—	—	—	110	115	14	20	30	60	82	56	87	83	—
11. Washington Court House, Ohio[a]	12/58	10,560[d]	1.3	—	—	—	—	—	—	248	188	47	50	27	36	74	59	81	73	—

Treatment Plant	Primary Sedimentation				Trickling Filters			Disinfection	
	Surface Overflow Rate (gpd/sq ft)	Raw Sludge			Hydraulic Loading (gpd/sq ft)	BOD Loading (lb/day/1,000 cu ft)	Recirculation (%)	Cl_2 Dosage (mg/l)	Effluent Quality (MPN/ml)
		Volume (cu ft/mil gal of sewage)	Dry Solids (lb/mil gal of sewage)	Solids Conc. (%)					
1. Alexandria, Va.[a]	—	715	1,520	3.4	358	36	140	—	—
2. De Kalb, Ill.[a]	428	—	—	—	217	14	176	—	—
3.	—	—	—	—	—	—	—	—	—
4. ↓ [b]	487	678	—	—	41	7	0	—	—
5. Fond du Lac, Wis.[b]	—	—	—	—	—	—	0	—	—
6.	—	—	—	—	—	—	0	—	—
7. ↓	—	—	—	—	—	—	0	—	—
8. Santa Rosa, Calif.[c]	1,450	309	1,085	5.6	557	66	90	—	—
9. Walla Walla, Wash.[f]	—	422	1,082	4.1	—	—	—	1.4	—
10. Walla Walla, Wash.[f]	—	389	1,070	4.6	—	—	—	1.5	—
11. Washington Court House, Ohio[a]	692	—	—	—	—	—	—	—	—

TABLE II.—*Continued*

Treatment Plant	Sludge Digestion													Sludge Filtration				Operating Cost ($/mil gal)
							Supernatant		Gas									
	VS Loading (lb/day/1,000 cu ft)	VS Red. (%)	Temp. (°F)	Vol. Acids (mg/l)	Alk. (mg/l)	pH	Volume (cu ft/mil gal of sewage)	Solids Conc. (mg/l)	Produced (cu ft/day/cap)	Produced (cu ft/lb VS fed)	Used (%)	Heat Value (Btu/cu ft)	CO_2 (%)	Dry Yield (psf/hr)	$FeCl_3$ Fed (%)	$Ca(OH)_2$ Fed (%)	TS in Cake (%)	
1. Alexandria, Va.[a]	50	61	—	—	—	—	470	5,380	—	12.4	63	600	34	6.9	2.6	8.4	24	37.92
2. De Kalb, Ill.[a]	—	—	—	—	—	—	—	—	—	—	—	—	—	—[g]	—	—	—	—
3. ↓	—	—	—	—	—	—	—	—	—	—	—	—	—	—[g]	—	—	—	—
4. [b]	—	—	—	—	—	—	—	—	0.75	—	—	—	—	—[g]	—	—	—	33.30
5. Fond du Lac, Wis.[b]	—	—	—	—	—	7.6[h]	—	—	1.5	—	96	—	—	2.1	4.9	34.6	28	102.14
6.	—	—	—	—	—	7.6[h]	—	—	1.79	—	81	—	—	2.9	4.0	26.6	31	91.50
7. ↓	—	—	—	—	—	7.3[h]	—	—	2.24	—	93	—	—	2.9	4.3	26.4	31	86.30
8. Santa Rosa, Calif.[c]	42	—	89[e]	—	—	—	243	—	—	7.3	—	—	35	—[j]	—	—	—	35.89
9. Walla Walla, Wash.[f]	—	67	97	—	—	7.0	—	—	—	—	—	—	—	—[g]	—	—	—	15.16
10. Walla Walla, Wash.[f]	—	69	96	—	—	7.1	—	—	—	—	—	—	—	—[g]	—	—	—	13.81
11. Washington Court House, Ohio[a]	—	—	95	—	—	—	—	—	—	—	—	—	—	—[g]	—	—	—	41.20

[a] High-rate filter.
[b] Low-rate filter.
[c] High-rate filter and oxidation ponds.
[d] 1950 census population.
[e] Does not include subsequent BOD removal in oxidation ponds.
[f] Two-stage filtration; first stage is high-rate; second stage is low-rate.
[g] Drying beds used.
[h] Supernatant.
[i] At middle of primary.
[j] Drying beds and lagoons used.

Park, Calif., is responsible for an important advance in the District's maintenance program. For the six-month period immediately prior to the purchase of power equipment 158 sections of sewers were rodded. During six months' operation with a power rodder 1,186 sections of sewers were cleaned; a 750 per cent increase with no increase in manpower.

During the past 20 years at Buffalo, 18,854 sewers, with a total aggregate length of 13,566,815 ft have been cleaned. A six-year comparative summary of sewer-cleaning costs is listed in Table IV. Table V summarizes cleaning costs for street inlets and catch basins.

Skimmings

Operating experience and laboratory investigations at the East Bay Municipal Utility District's (Oakland, Calif.) treatment plant reveal that skimmings are digested very poorly. Also, skimmings are believed to contribute very greatly to the formation of scum in digesters. Examination of digester scum shows the formation to be composed of two distinct layers. The upper layer is dark and oily-like and floats on a tough, thick mat of "greasy" solids containing fibers, hair, rubber, paper, plastics, wood, and other floatables.

Alternate methods of skimmings disposal studied include incineration, burial, and processing to recover tallow. Incineration was studied on a pilot-plant scale. The skimmings have a high heat value and were found to burn readily with very little ash. Disposal by burial is being evaluated and a contract with a rendering company is under negotiation.

Whichever method of disposal is selected, a method of collecting skimmings must be devised. So far, investigations point to a flotation system as the most promising. Skimming would be moved to the flotation unit by the plant effluent. Operation of a prototype system is planned to begin shortly.

TABLE III.—Operating Results from Nine Primary Plants

Treatment Plant	Operating Yr Ending	Est. Pop. Served	Sewage Volume				Sewage Temp. (°F)			Sewage Strength (mg/l)				Eff. of Treat. (%)	
			Avg (mgd)	Max Day (mgd)	Min Day (mgd)	Per Cap (gpd)	Avg	Max	Min	Influent		Effluent			
										BOD	SS	BOD	SS	BOD	SS
1. Buffalo, N. Y.	6/58	598,000	124.	257.	70.	207	60	77	40	124	134	88	89	29	34
2. Defiance, Ohio	12/58	11,255[a]	0.8	—	—	193	—	—	—	193	132	147	57	24	57
3. Detroit, Mich.	6/58	2,661,000	527.	—	—	202	—	—	—	123	226	79	109	36	55
4. EBMUD (Oakland), Calif.	6/58	630,000	72.	206.	41.	114	—	—	—	244	248	176	99	29	58
5. Kenosha, Wis.	12/58	66,000	11.8	—	—	179	45	—	—	75	119	46	52	39	56
6.	12/57	61,000	13.9	—	—	228	45	—	—	74	131	48	59	35	54
7. →	12/56	59,000	12.5	—	—	210	46	—	—	89	134	58	61	35	55
8. Menlo Park, Calif.	6/58	41,000	3.4	—	2.5	83	—	—	—	242	217	162	87	33	60
9. New Rochelle, N. Y.	12/58	—	12.0	6.8	—	—	—	—	—	90	103	62	45	31	56
10. Oshkosh, Wis.	10/58	43,000	5.1	—	—	119	—	—	—	172	155	112	81	36	50
11.	10/57	43,000	5.6	—	—	130	—	—	—	161	160	93	74	40	52
12. →	10/56	44,000	5.8	—	—	132	—	—	—	136	157	87	74	37	51
13. Washington, D. C.	6/58	802,178	186.	—	—	—	—	—	—	129	185	94	89	27	52

TABLE III.—*Continued*

Treatment Plant	Grit Removed (cu ft/mil gal)	Primary Sedimentation				Disinfection	
		Surface Overflow Rate (gpd/sq ft)	Raw Sludge				
			Volume (cu ft/mil gal of sewage)	Dry Solids (lb/mil gal of sewage)	Solids Conc. (%)	Cl_2 Dosage (mg/l)	Effluent Quality (MPN/ml)
1. Buffalo, N. Y.	1.8	—	187	612	5.2	4.3	1,670
2. Defiance, Ohio	0.2	—	575	1,440	4.0	—	—
3. Detroit, Mich.	—	—	195	975	8.0	3.8	1,500
4. EBMUD (Oakland), Calif.	1.3	—	354	1,380	6.1	—	—
5. Kenosha, Wis.	0.8	—	155	835	8.6	—	—
6. ↓	0.8	—	131	705	8.6	—	—
7.	1.1	—	146	735	8.0	—	—
8. Menlo Park, Calif.	2.3	602	578	1,660	4.6	—	—
9. New Rochelle, N. Y.	1.0	936	368	—	—	10.0	<100
10. Oshkosh, Wis.	0.7	—	180	630	5.6	—	—
11. ↓	0.7	—	155	446	4.6	—	—
12.	0.9	—	191	573	4.8	—	—
13. Washington, D. C.	2.0	—	175	803	7.1	—	—

Treatment Plant	Sludge Digestion													Sludge Filtration				Operating Cost ($/mil gal)
	VS Loading (lb/day/1,000 cu ft)	VS Red. (%)	Temp. (°F)	Vol. Acids (mg/l)	Alk. (mg/l)	pH	Supernatant		Gas					Dry Yield (psf/hr)	$FeCl_3$ Fed (%)	$Ca(OH)_2$ Fed (%)	TS in Cake (%)	
							Volume (cu ft/mil gal of sewage)	Solids Conc. (mg/l)	Produced (cu ft/day/cap)	Produced (cu ft/lb VS fed)	Used (%)	Heat Value (Btu/cu ft)	CO_2 (%)					
1. Buffalo, N. Y.	57	77	94	—	—	7.2[b]	126	6,000	—	10.3	—	591	34	—	4.1[c]	20.2	40	18.22
2. Defiance, Ohio	—	72	—	—	—	—	—	—	—	—	—	—	—	—[d]	—	—	—	—
3. Detroit, Mich.	—	—	104	—	—	—	—	—	—	6.6	—	—	—	2.9	1.7	15.5	35	—
4. EBMUD (Oakland), Calif.	140	61	—	154[b]	3,195[b]	7.1[b]	345	24,000	1.06	9.3	19	585	36	—[e]	—	—	—	—
5. Kenosha, Wis.	75	81	90	—	—	6.7	—	5,200	0.56	5.2	95	680	—	—[f]	—	—	—	18.75
6. ↓	69	78	90	—	—	6.7	—	6,000	0.60	6.1	96	680	—	—[f]	—	—	—	18.02
7.	67	69	91	—	—	6.9	—	4,800	0.71	7.3	97	680	—	—[f]	—	—	—	19.05
8. Menlo Park, Calif.	42	—	—	—	—	7.1	500	—	1.03	9.3	39	—	35	—[g]	—	—	—	30.48
9. New Rochelle, N. Y.	17	75	—	270	1,532[b]	6.5	—	—	—	—	—	—	34	6.3	3.0	7.4	28	—
10. Oshkosh, Wis.	—	—	—	—	—	—	—	—	0.82	—	97	—	—	—[d]	—	—	—	—
11. ↓	—	—	—	—	—	—	—	—	0.78	—	98	—	—	—[d]	—	—	—	—
12.	—	—	—	—	—	—	—	—	0.56	—	—	—	—	—[d]	—	—	—	—
13. Washington, D. C.	—	—	94	—	3,010[b]	—	—	11,190	—	—	59	574	35	5.8	4.4	0	32	10.42

[a] 1950 census population. [b] Supernatant. [c] $AlCl_3$. [d] Drying beds used. [e] Ocean disposal. [f] Drying beds and lagoons used. [g] Lagoons used.

TABLE IV.—Sewer-Cleaning Costs at Buffalo, N. Y.

Fiscal Year	No. of Sewers	Total Length (ft)	Cost (¢/ft)
1953	690	584,168	13.3
1954	601	459,703	15.4
1955	686	510,327	15.5
1956	944	710,122	14.9
1957	946	690,096	16.0
1958	704	504,665	20.9

TABLE V.—Cleaning Costs for Street Inlets and Catch Basins at Buffalo, N. Y.

Fiscal Year	Street Inlets		Catch Basins	
	No. Cleaned	Cost per Inlet ($)	No. Cleaned	Cost per Inlet ($)
1954	26,739	1.45	792	1.20
1955	59,347	0.92	754	1.28
1956	68,190	0.80	682	1.44
1957	54,890	1.10	678	1.67
1958	51,165	1.19	447	1.91

At Detroit, grease and other accumulations skimmed from the sedimentation tanks are destroyed on a lower hearth of the incinerator. This method of disposal has been used for the past six years and is considered successful.

Sludge Digestion and Handling

De Kalb, Ill.

Digester startup at De Kalb began without incident but in a very short time trouble developed which plagued operations for eight months.

On Jan. 16 heating of the digester contents was begun. On Jan. 22 seed sludge from the old digester was transferred to the new unit and by Feb. 3 burnable gas was being produced. Later in February, however, structural and mechanical failures made controlled digestion next to impossible. During April and June a total of 2,400 lb of lime was added at the rate of from 100 to 200 lb/day in an attempt to raise the pH. The digester was allowed to rest intermittently but improvement of conditions did not result. By late September the volatile acids in the digesting sludge reached 3,800 mg/l and gas production continued to decrease.

About the same time the new digester was giving trouble, the old digester, where no attempt at control was made, gradually started to produce gas in large quantities and the volatile acids concentration of its contents remained low. With these observations in mind all circulation and heating of the new digester were stopped on Sept. 25 and all raw sludge was pumped to the top of the old unit. From the bottom of this unit, digesting sludge, equal to a 3-in. depth of the new digester, was transferred to the top of the new unit. This was done daily. The plan was to gradually develop a volume of rapidly digesting sludge having a relatively low volatile acids content without mixing, heating, or the addition of raw solids to cause an increase in volatile acids.

Sludge in the old digester had a temperature of 70°F and that in the new unit, 85°F. However, no difficulty that could be attributed to this temperature difference seemed to occur. By Oct. 4, 10 days after the sludge transfer began, gas production in the new unit increased from 2,000 to 4,000 cu ft/day and some evidence of foaming was observed. Also on Oct. 4, a small amount of raw sludge (700 gal) was added to the new digester and the contents were circulated for 15 min. On Oct. 6 the last transfer of sludge from the old unit was made. Also on this date the digester contents had the following characteristics:

Item	Bottom of New Digester	Bottom of Old Digester
Temp. (°F)	88	67
Volatile acids (mg/l)	3,500	560
pH	6.9	6.8
TS (%)	9.25	7.15
VS (as % of TS)	45	45

After Oct. 4, raw sludge was added and the digesting solids were circulated on an every-third-day schedule. By

Oct. 12 gas production was good and the raw solids addition was increased. This procedure was followed for the month of October at the end of which the sludge in the circulation zone was found to have a pH of 7.3 and a volatile acids content of 760 mg/l. Gas production was steady at about 28,500 cu ft/day. Thus normal conditions were finally established.

East Bay Municipal Utility District, Oakland, Calif.

At East Bay, sand accumulation in the digesters continues to be one of the major operating problems. Laboratory work shows that more than 50 per cent of the sand passes through a 200-mesh screen and laboratory attempts to separate the sand from raw sludge have not yet been successful. Both aeration and pressure flotation have been tried.

A major addition to the East Bay plant has been a 2.25-mil gal digester (Figure 1) incorporating several new design features. For example, nearly all the piping which is normally inside a digester was placed either around the outside or on the cover of the new unit. The absence of this internal piping permits the cover to be lowered 15 ft below the minimum elevation of the covers on the other three digesters. Manholes were provided at a level just below the "down position"; at just above ground level; and at a level just above the "down position." Sludge can be added or withdrawn at any of 15 different locations or combinations thereof. The scum blanket can be broken up by either gas recirculation or supernatant injection, both through numerous openings in the floating cover. The 8-in. gas and scumbreaker lines on the cover are carried over the tank wall by 15 ft of flexible rubber hose.

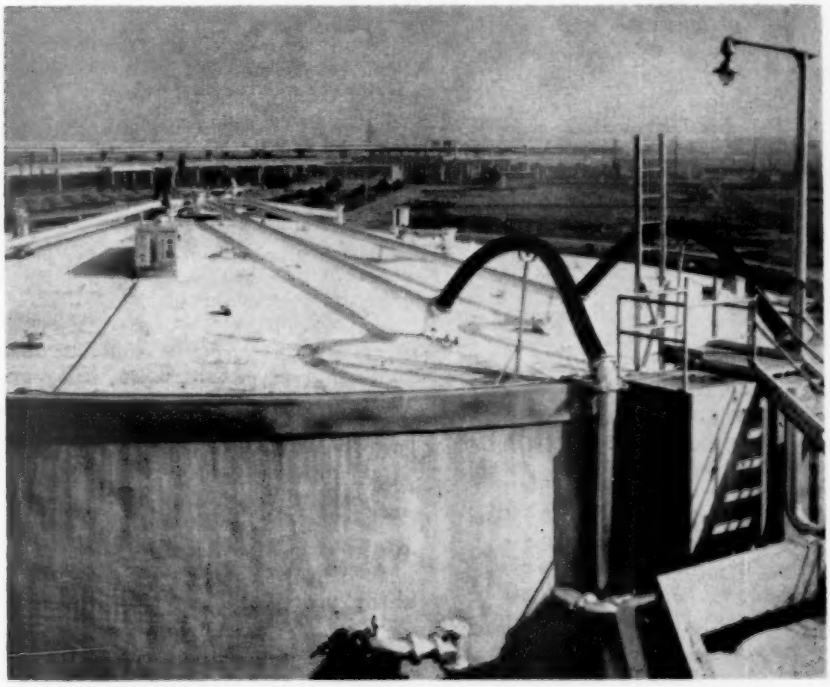

FIGURE 1.—EBMUD's new digester. Notice flexible piping in right foreground.

Alexandria, Va.

During April an inspection of the primary digester at Alexandria revealed that a scum blanket had formed to a thickness of 18 in. Although the blanket caused no operating problem, the liquid level of the tank was lowered slightly to bring the scum layer within closer reach of the draft-tube inlets. A substantial reduction in the scum thickness followed this adjustment.

Also at Alexandria, a piping change was made during the year to permit the discharge of the filtrate from vacuum dewatering to the elutriation tanks. This modification essentially resulted in the reclamation of residual amounts of lime and ferric chloride which were formerly lost to the plant sewerage system.

Jackson, Mich.

The six digesters at Jackson function as two three-stage units. This method of operation is claimed to be superior in many respects. The digested sludge has a solids content of about 9.4 per cent of which about 42 per cent is volatile matter.

Washington, D. C.

Ten of 12 digesters at the Washington, D. C., plant were operated in parallel as single-stage digesters. Five of these were dosed in sequence on alternate days. On the intervening days room was made for the next addition of sludge by withdrawing either supernatant or bottom sludge. Tank-level measurements appropriate to these separate operations were used to compute fluid volumes added to and removed from the digesters. With this information it was possible to follow the digestion process rather closely.

Two of the 12 digesters were used to settle supernatant from the other tanks. This practice resulted in a reduction of supernatant suspended solids from a high value of 1.5 to 2.0 per cent to a value of less than 0.5 per cent while producing a sludge with a solids concentration of 8 per cent.

New Rochelle, N. Y.

At New Rochelle a somewhat unusual problem is caused by the high solids content in the sludge from the secondary digester. At times the solids content is as high as 11.5 per cent. Such a sludge is difficult to pump; sometimes it must be diluted with treated sewage. After conditioning chemicals were added, similar difficulties were encountered in moving the sludge to the filter. This problem was solved by raising the mixing tank to increase the allowable head loss.

Detroit, Mich.

Detroit has developed a miniature vacuum filter to study the filterability of different sludges as well as the effects of modifications in sludge conditioning methods.

Buffalo, N. Y.

At Buffalo waste lime from an acetylene manufacturing plant is used in sludge conditioning along with waste aluminum chloride from another local source. This latter chemical has satisfactorily supplanted ferric chloride.

Use of Dynel filter cloths has been continued as a replacement for the flannel-type. An average useful life of 1,400 hr has been recorded for Dynel, whereas the useful life of flannel is about 180 hr.

Grease and carbonates imbedded in filter cloth pores have been removed by acid and detergent washings. Carbonate encrustations in filtrate piping have been removed by the addition of muriatic acid.

Painesville, Ohio

The charge for dumping septic tank sludge at the Painesville sewage treatment plant is $5/1,000 gal or fraction thereof. This service was first offered by the plant on Sept. 13 and by the end of the year revenue from this source totaled $1,585.

Vacuum filters at this plant have been operated successfully using only one vacuum pump and one filtrate pump to operate two filters. This feature, which cut power costs by about 50 per cent, was made possible by the interconnection of the filtrate receivers.

Kenosha, Wis.

At Kenosha considerable savings were made by pumping digested sludge to a diked-off area within the plant grounds. The only preparations made at the site are leveling and diking. The sludge is pumped to this area only during the winter. Experience shows that by fall the sludge is dry enough to be moved with a front-end loader. During other seasons sludge is pumped to both a privately owned marsh and conventional sand beds. Sludge from the sand beds is also removed using a front-end loader. Mechanical removal results in a slightly greater loss of sand, but what was formerly a seven-month job for two men is now a routine, minor chore.

Santa Rosa, Calif.

Centrifuging of digested sludge was tried for a two-month period at Santa Rosa. It was found that when hauling costs and capital outlay were added to operating costs this method of sludge drying was not economically feasible. Further investigation of other methods of sludge disposal indicated that composting would be economical if the work was done by contract. Accordingly, a contract was signed for use of the "Tillo" process and in May 1958 the contractor had facilities ready for use.

Trickling Filters

Late in 1957 rotary distributor arms were installed on both of the old, fixed nozzle beds at De Kalb, Ill., thus converting each filter to high-rate operation. The existing dosing tanks will function as head boxes into which the recirculating flow will be discharged.

ECONOMICAL PRACTICES IN SEWAGE TREATMENT PLANT OPERATION *

By E. J. Beatty

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This is one of four papers collectively forming a sewage treatment cost reduction symposium. The papers on activated sludge and digestion processes and on sewage treatment plant construction have already been published in This Journal (**31**, 4, 399; **31**, 4, 406). The fourth paper on over-all regulatory considerations appears on page 662 of this issue.

Those who have the responsibility for maintaining and operating sewage treatment plants are constantly faced with the problem of finding ways and means of financing the necessary costs for maintenance and operation. The main items under most operating budgets are labor, maintenance, utilities, and overhead expenses.

Importance of Design

The utility item in the budget, in general, is a fixed cost and there is usually very little that can be done toward reducing it. Overhead items, such as insurance and pensions, are also fixed items. It is the designing

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engineer who can, by proper design, provide one of the most effective means of reducing the operating costs of the finished sewage treatment plant. If, in laying out the original plant, he would have frequent conferences with the operating personnel it would undoubtedly result in the provision of many features, at a reasonable cost, which would greatly reduce the labor costs in plant operation. Some of the specific ways in which this can be done are discussed below.

Grit Chambers

It should be possible to provide grit chamber facilities ahead of bar screens or underwater screenings grinders to reduce the amount of wear resulting from handling grit through these units. A grit chamber should be installed in such a manner as to eliminate the need for daily loading and hauling of grit or the constant parking of trucks to receive the discharge from grit washing facilities. Above all, a mechanical means of handling of grit should be made available to eliminate the large amount of labor required for the hand cleaning of grit chambers. When hand cleaning is necessary the tendency is to neglect cleaning the grit chamber. This results in gross deposits of solids in the digestion facilities which inevitably cause operating problems and the eventual need for extensive cleaning at considerable expense. If, however, grit chambers are installed ahead of bar screens or underwater screenings grinding facilities there will be a major reduction in the amount of repair necessary and in the labor costs involved in maintaining these facilities.

Primary Clarifiers

In many plants a large number of small-capacity primary clarifiers have been installed although two or three large units would provide the same treatment efficiency and would eliminate many maintenance problems and much of the labor time required for pumping and skimming the multiple units.

Sludge Pumping Facilities

Sludge pumping facilities should be made as flexible as possible so that more than one operating procedure can be carried out by the plant personnel at the same time. This reduces the amount of labor required for pumping, transferring, and withdrawing the sludge and supernatant. Many plants have been designed which do not provide this flexibility and, when only one operating procedure can be carried out at a time, the operator must spend the major portion of his day changing valves and waiting for the pump to carry out the necessary movement of sludge or supernatant. A few valves and fittings might make considerable difference in the operating time required and they can be installed much more economically at the time of original construction than at a later date. Some of these design features are not apparent in the general layout of a treatment plant in planning stage. sult of actual experience in operation on the part of the designing engineer or through cooperation with the staff which will have control of the operation of the plant.

Sludge Drying Beds

The trend today is toward the elimination of the open sludge drying beds. This is due to the fact that the operation of sludge beds is an expensive proposition, not only in the original cost but also in the cost of removing the sludge and replacing the sand. Recently there has been reference to an open sludge bed with a paved bottom (1) from which dry sludge is removed by utilizing end loaders or other such equipment. Apparently use of this type of sludge bed has been limited to the more arid sections of the country and little, if any, experimental work has been carried out in more humid areas. The Urbana and

Champaign Sanitary District hopes to reconstruct two of its existing sludge beds in 1959 to test out this method of sludge drying.

Deep Sludge Lagoons

At the present time it appears that the most economical method of sludge disposal, from the standpoint of operating costs, is the use of deep sludge disposal lagoons from which there is no intention of ever removing the sludge. This method has worked out very satisfactorily in locations where land areas and isolation permits the installation of this type of facility.

Shallow Sludge Lagoons

The Urbana and Champaign Sanitary District has experimented during the past seven years with the use of shallow sludge lagoons. These are large undrained areas which are leveled and diked and into which digested sludge is discharged over a period of time to a maximum depth not exceeding 12 to 15 in. It is possible to clean this type of lagoon yearly by the use of end loaders or other equipment of a similar type. The amount of labor required for cleaning these shallow lagoons is very small. During the years the experiment was being tried, good drying conditions prevailed most of the time but one rainy season was encountered and at this time it was necessary to remove the sludge while it was still quite high in moisture content. In general it is felt that this type of installation has proved itself to be entirely satisfactory for use in central Illinois.

Vacuum Filters

The installation of vacuum filters in many of the larger plants has proved to be satisfactory but their economy, from an operating standpoint, is open to question in the case of the very small plants. The design of vacuum filters has improved steadily but a large amount of labor is still required for the operation of these filters and the cost of chemicals for the filtering process is quite high. It is believed that the engineer, in recommending the installation of vacuum filters, should submit a detailed operation cost estimate for the review and consideration of the governing bodies. This should be studied carefully before vacuum filters are decided on. Once vacuum filters are installed there still remains the problem of disposal of the sludge cake which, under normal conditions, would have approximately 65 to 70 per cent moisture. Unless considerable land area is available for stock piling this filter cake, it might create a major problem of ultimate disposal and, in the end, it might be necessary to install cake-drying or complete incineration facilities. Both of these processes involve considerable labor cost as well as costs for auxiliary fuels and maintenance.

Aeration Equipment

The Urbana and Champaign Sanitary District is now in the process of constructing major additions which will include activated sludge facilities to operate in parallel with the existing trickling filter. Investigation into the operating costs of various types of aeration equipment led to the conclusion that the most desirable type of installation would be one that requires only minor air filtration in front of the blowers. Attention was also given to the ability of the unit to dispense air into the activated sludge tanks in a manner which would not require constant cleaning or the alternative of pressure buildup in the air lines. Preliminary study of the problem included visits to existing plants. In some of these, the aeration equipment was in the process of being cleaned and it was apparent that cleaning is a necessary routine at regular intervals and one which requires a considerable amount of labor. Sparger-type aeration units were finally selected and it is hoped that their installation will eliminate this particular operating expense.

Spare Parts

The stocking of repair parts, so as to have them available when needed, can tie up a considerable portion of the operating budget. If the designing engineer could duplicate certain pieces of equipment, such as electrical controls, gear reducers, and other items of this type, there could be a major reduction in the number of repair parts required to be kept in the storeroom for emergency repairs. It should be possible to carry out this procedure without detrimental effect to the over-all operating efficiency of the sewage treatment plant.

The above items are only a few of the design features which can save on operating costs. The consulting engineer, who has control in the layout of the sewage treatment plant, should strive to include such items in his design and should recommend the inclusion of labor-saving equipment, where feasible, to be installed at the time of the plant's construction.

Tools and Equipment

One important operating economy, over which the operating personnel has control, is the procurement of the tools and equipment needed to carry out routine duties and maintain the treatment plant in satisfactory condition. The use of proper tools and other portable equipment makes it possible to reduce the man hours of labor required for repairs or improvements. A modern sewage treatment plant cannot be operated with a screw driver, monkey wrench, and sledge hammer. Good mechanical procedures are required and repairs can be made satisfactorily only if the proper tools are available.

Pumping Equipment

No sewage treatment plant should be operated without the aid of suitable auxiliary portable pumping equipment. The pump should be large enough to dewater a tank or other portion of the plant in a short period of time so repairs can be made promptly and the plant put back in operation without the need for extended bypassing.

Crane Use

An interesting experience which the Urbana and Champaign Sanitary District had with one piece of portable equipment came about as a result of its being given, in 1950, the responsibility for maintaining approximately seven miles of open storm ditch which flows through the two municipalities and through the heart of the University of Illinois. After considerable study and investigation of the requirements it was decided that some type of equipment should be purchased for removal of deposited debris and silt from this open drain so as to eliminate plugging of culverts and bridges. After further study a hydraulically operated crane * equipped with a ¼-yd clamshell was purchased. This unit, mounted on a six cylinder truck, cost approximately $9,000 in 1951. At the time of purchase it appeared this unit would be used only about four months of the year and there was some doubt as to whether its value would justify the cost. However, in actual experience, there has been hardly a week throughout the year, even in mid-winter, that this unit has not been used.

One of the time-consuming and dirty operations at the Urbana-Champaign treatment plant was the removal of large amounts of scum which collected in the gas vents of the old Imhoff tanks. It has been found that this material can be removed with the crane bucket, discharged into dump trucks, and immediately disposed of at the municipal dumping grounds. In 1953, in designing the aerated grit chamber, advantage was taken of the availability of this piece of equipment. The grit chamber was so designed that the grit collected in a trough in the bottom of the grit chamber, from which it could be removed periodically with the crane

* "Hydrocrane," manufactured by the Bucyrus-Erie Co., South Milwaukee, Wis.

and disposed of at the municipal dump. The saving of the cost of the mechanical equipment which would otherwise have been required in the grit chamber was almost sufficient to pay for the cost of the truck and crane. There is an additional cost advantage in that it is no longer necessary to tie up a dump truck seven days a week for the purpose of handling grit.

Another disagreeable operating chore has been eliminated through the use of the crane; the removal of grit from the grit chamber ahead of the inverted siphon on the intercepting sewer system. Use of the crane and one truck makes it possible to clean this siphon grit chamber in a period of 30 min. Previously several days of disagreeable hand labor were required and during this period it was necessary to bypass the sewage to the receiving stream.

At the present time, seven sewage lift stations in the outlying areas of the Urbana and Champaign Sanitary District are being constructed. All of these units are being provided with a grit chamber ahead of the wet well and with screening facilities which can be cleaned by use of the crane. It has also been found that this unit can be used readily for the removal of dead trees from the park area of the plant. Additions and repairs to plant underground piping facilities and minor repairs along the intercepting sewer system are also made with its use. Actually, the staff at the Sanitary District, if faced with a choice, would rather give up almost any other piece of equipment it has available than to part with the crane. It has paid for itself many times in labor costs and has made it possible for the operating crew to do considerable repair work and to make some minor extensions without having to call in outside contractors.

In making repairs to equipment and machinery it is undesirable to be in the position of constantly having to borrow the necessary tools to carry out routine operation and maintenance duties. The cost of the necessary tools will be more than compensated for by the savings which will result from an adequate preventive maintenance program.

Operating Staff

In plants where those in charge of sewage treatment operation also have the responsibility for hiring the operating staff, it should be possible to secure the kind of personnel having the necessary skills and aptitudes which will fit in with the operating scheme of the individual plant. The only difficulty likely to be encountered is the pay scale. By picking personnel with various skills it will be found that many repairs and plant improvements can be made without the need for calling in outside mechanics or contractors. Some plants are handicapped, however, by having to accept an operating crew recommended or employed by administrative officials. No economy is effected if these employees' only qualifications are need of a job or having worked to secure the election of certain officials.

Repair Parts

It should be possible to secure repair parts for mechanical equipment (such as pumps, gear reducers, and chains) within a week from almost any manufacturer supplying equipment. However, sometimes this week stretches out to a period of three to four months. It is difficult to understand why it should take this long to secure repair parts for a standard piece of equipment. But since this does occur, it becomes necessary for the sewage treatment plant to stock certain of these parts. Unless this is done, the operator is often obliged to operate a piece of equipment beyond a point of economy and complete failure of the equipment may take place before a repair part is secured. This investment could be eliminated if more rapid service were available.

During the past few years there has been a tendency on the part of some manufacturers of sewage treatment, and other equipment, to require that all repair parts be ordered from a jobber who supplies a territory of any-

thing from ten counties up to two states. This method is likely to result in further delay in securing parts since, more often than not, the district jobber does not have all of the parts on hand. He must then order them from the supplier and wait to receive the parts before they can be shipped to the consumer. This may double or triple the length of time necessary to secure these parts and certainly does not reduce the cost of repair parts.

At the time equipment is purchased, a parts list is nearly always made available by the manufacturer. This usually refers only to the manufacturer's parts list number and does not give direct information on bearings, oil seals, grease seals, etc., all of which are standard stock items at wholesale and retail houses. Replacement would be made very much simpler if, when the manufacturer's stock drawings and parts lists indicate bearings, a reference could be made to a bearing manufacturer's number. If this were to be done, the item could probably be picked up locally and made available for repairs without the necessity for tearing down the unit to find out the number of the bearing and then waiting for it to be secured. This is also true of grease seals and oil seals. There appears to be no reason why the assembler or manufacturer of the major equipment should expect such normal maintenance items to be purchased through him.

Landscaping

Many references have been made in literature to the fact that visitors at sewage treatment plants "smell with their eyes" and that beautiful landscaping, shrubbery, and flowers go a long way to create a desirable impression. The Urbana and Champaign Sanitary District subscribes to this belief. However, the maintenance of a large park acreage in connection with the sewage treatment plant definitely increases the over-all cost of sewage treatment. Where such large park areas are provided in connection with sewage treatment plants, it is believed that this cost should not be charged against the actual cost of sewage treatment plant operation but rather should be considered as a separate park maintenance cost.

Planning for New Industries

Nearly all municipalities are interested in securing new industries because they provide more labor opportunities in the community. Frequently, however, no consideration is given to the important matter of whether or not the industry is of a type which produces a large volume of waste that is difficult to dispose of. In the enthusiasm of securing a new industry, officials are prone to agree to take the industrial waste through the sewers and sewage treatment facilities without giving any thought to the difficulties which may result and to the increased cost of maintaining and operating sewers and sewage treatment facilities under these new conditions. Some types of industrial wastes can be dumped into existing collection systems and treated at the existing treatment facilities without difficulty. But other industrial wastes may make new demands on the system.

Conclusions

In general, an economically operated sewage treatment plant will have the following characteristics:

1. It will be well designed, with operating costs having been given due consideration by the design engineer at the time of planning.
2. It will be well equipped with the necessary tools and equipment needed for efficient performance of operation duties, maintenance, and repairs.
3. It will be manned by a well-qualified staff working under conditions which develop a desire for permanency and a determination to produce good results.

Reference

1. Lynd, E. R., "Asphalt-paved Sludge Drying Beds." THIS JOURNAL, **28**, 5, 697 (May 1955).

TIPS AND QUIPS

Cleaning Electric Motors *

Costs of cleaning large electric motors have been reduced as much as 75 per cent through on-site use of non-flammable, non-explosive, "Freon" solvents in tests conducted by the du Pont Company.

In addition to cost and safety advantages, these solvents will not attack insulating materials and varnishes used on motor windings. The fact that they permit in-place cleaning, rather than dismantling of motors for cleaning in the shop, reduces equipment down-time and makes practical a continuing program of preventive maintenance.

For example, at one of the du Pont plants, an enclosed 600-hp motor was cleaned in one day, without dismantling, at solvent cost of about $80. Previously, cleaning the same motor cost nearly $400, including dismantling for shipment to an off-plant cleaning and servicing site.

Procedure for cleaning the motor with "Freon" solvent was as follows: End bells and coil shields were removed from motor to permit access to armature coil and stator area. Solvent was then sprayed on coating of oil, grease, and dirt that had accumulated on coil and stator surfaces. Most of the softened accumulation was brushed off with a small paint brush.

Final cleaning was accomplished by high-velocity power-spraying of solvent over coil and stator and removing the solvent-dirt mixture from the bottom of the motor housing.

A faster method could be used where the housing permits the introduction of liquid solvent into a liquid-tight housing around the bottom of the motor. In this way the motor could be turned over in a liquid bath. After draining, the motor should be ready for use within a few hours.

For further information write to Public Relations Department, 8531 Nemours Bldg., E. I. du Pont de Nemours & Co., Inc., Wilmington, Del., Att.: Mr. F. R. Zumbro.

* From *Power Industry*, **75**, 1, 6 (1959).

Digester Cleaning

Digester cleaning in Philadelphia, Pa., as in most places, is a particularly difficult task. But at the 1958 Operators' Forum, Ralph A. Hoot, Plant Superintendent, had a suggestion that should be helpful to the operator faced with the job of removing the bottom accumulation after pump suction has been broken. Mr. Hoot reported that when they had arrived at that point in cleaning a 110-ft digester in Philadelphia, a mechanic suggested that a water-operated ejector be connected to the suction side of the pump. This solved the problem and now a digester can be cleaned and put back in service within two weeks.

Bloodgood Abroad

Last summer Prof. Don E. Bloodgood of Purdue University presented the paper, "Treatment of Industrial Wastes in the United States," before the Institute of Sewage Purification. In the discussion of this paper, Mr. A. Holroyd, Manager, Sewage Disposal Department, Wolverhampton, England, pointed out that since the United States covered 3,000,000 square miles and the paper was about 6,000 words long, one could say that each word covered the industrial waste problems in 500 square miles. Mr. Holroyd further suggested that "If the same calculation were applied to Britain one would need to compress the amount of our comparable problems into 150 words!"

We shall always wonder about what Professor Bloodgood would have said in a two-word speech in Luxembourg and what he would have thought about during a period of silence in Monaco.

News and Notes

Of Persons and Activities in the Wastewater Field

Gordon E. McCallum has been placed in charge of the newly created Division of Water Pollution Control of the U. S. Public Health Service. In this position he will be directly responsible to the Surgeon General. In his former post of Chief of Water Supply and Water Pollution Control Branch of the Division of Sanitary Engineering Services, Mr. McCallum has become a familiar figure in the sanitary engineering field.

E. Robert Baumann, Professor of Sanitary Engineering at Iowa State College, has been granted a one-year Science Faculty Fellowship by the National Sanitation Foundation, beginning September 1, 1959. He will spend the year pursuing postdoctoral study in biochemistry and bacteriology at an English university.

Robert T. Steindorf, formerly Manager of the Conveyor and Process Equipment Division of **Chain Belt Company,** Milwaukee, Wis., has been made Director of Research and Development.

Lewis S. Finch, Chief Engineer and Vice-President of the Indianapolis Water Company, and current AWWA President, was named "Engineer of the Year" by the Indiana Society of Professional Engineers. He is a Past Director of the Federation.

Carl E. Schwob, Chief of the U. S. Public Health Service Division of Water Pollution Control from 1945 to 1955, and Special Consultant since 1955, has retired, for health reasons. He received the Federation's Bedell Award in 1955.

Greeley and Hansen have moved their quarters to 14 East Jackson Boulevard, Chicago 4, Ill.

Philip F. Morgan, Professor of Sanitary Engineering at the State University of Iowa, Iowa City, is also Mayor of Iowa City.

Everett M. "Casey" Jones has been named Assistant to the Vice-President of Rockwell Manufacturing Company's Meter and Valve Division.

Nandor Porges, U.S.D.A. microbiologist at the Eastern Utilization Research and Development Division, Wynmoor, Pa., died recently in New Brunswick, N. J. He was a frequent Journal contributor, with dairy waste studies his principal interest.

Samuel Baxter, City Engineer of Philadelphia, was recently named as Philadelphia's "Engineer of the Year." He follows **Francis S. Friel** in this honor.

Jack W. Pratt has been appointed Eastern Sales Manager of the Eimco Corporation, with headquarters in Palatine, Ill.

Jay S. Grumbling has joined the staff of **Metcalf and Eddy,** Boston, Mass., as a Research Engineer, where he will work with **Dr. Clair N. Sawyer,** Director of Laboratories and Research. Mr. Grumbling was formerly Associate Editor of *Water and Sewage Works.*

Philip Abrams has joined Engineering Science, Inc. of Pasadena, Calif. He recently was project engineer for **James M. Montgomery** of Pasadena.

N. A. Sorenson, Superintendent of the Neenah-Menasha Sewerage Commission, Menasha, Wis., was recently elected President of the Conference of Wisconsin Sewage Works Operators.

The Florida Department of Water Resources has moved from the Capitol to State-Owned Building No. 5, at the corner of Gaines and Bronough Streets in Tallahassee.

Edward J. Kilcawley, Professor and Head of the Division of Soil Mechanics and Sanitary Engineering at Rensselaer Polytechnic Institute, has been appointed to the New York State Air Pollution Control Board.

Walker Process Equipment Inc., Aurora, Ill., in the second substantial addition within the past five years, recently added 13,000 sq ft to their manufacturing facilities.

Robert A. Nanz, President of Florida Chemists and Engineers, announces the move of the firm to new and enlarged facilities at 645 Rugby Avenue, Orlando, Fla.

Editorial

DEEDS AND DATA

Three months ago the first model of **DEEDS AND DATA**—the successor to "Interesting Extracts"—was launched. Now a new and bigger model is being displayed on page 743 of this issue of the Federation Journal. Featured in the report are tables which summarize 32 years of operating experience in 22 sewage treatment plants. Compiling these data and presenting them in this condensed form has been an interesting and rewarding task—but a very time-consuming one. Now we share with you the fruits of this experience in the hope that you will find the material interesting and the tabular presentation easy and convenient to use.

Over the years there has been a most gratifying response to requests for submission of annual reports to THIS JOURNAL. As time went on, however, the constant increase in the number of wastewater treatment plants, and a corresponding increase in the number of reports received from these plants, made it more and more difficult to find space in the Journal for publishing each report individually—as was done previously in "Interesting Extracts." Since reporting of all submitted operating data has always been the objective of the editors, some method of condensation had to be found.

To conserve space and to continue to bring Journal readers operating experiences of others, highlights from operating reports, together with appropriate tabulations of significant operating data, will now be found in the new section called **DEEDS AND DATA.** This is part of the Federation program to focus more attention on, and to strengthen the service to, a most important segment of Journal readers—the operating group.

At the present time **DEEDS AND DATA** is scheduled to appear three or four times a year. But much depends on the supply of raw material.

In preparing the tabular entries in this issue, the conversion of much information to the units of expression given in Manual of Practice No. 6 has been necessary. It is hoped by this means to stimulate more widespread adoption of the units recommended by the Committee on Sewage and Industrial Wastes Practice and approved by the Federation Board of Control. Journal abbreviations (THIS JOURNAL, **31**, 1, 121; Jan. 1959) have also been used and their general adoption is also strongly recommended in manuscripts as well as reports. It is felt that this will save time, reduce chances for error, and increase the understanding and knowledge of all.

In making any change in editorial policy, every effort is made to incorporate only changes which will be regarded as improvements by you, the reader. The only check we have on the soundness of such decisions, however, is reader reaction. Your comments and suggestions are not only very welcome—they are genuinely needed! You will be making a real contribution if you will give **DEEDS AND DATA** a comprehensive reading and then drop us a card or a letter expressing your reaction. This may well bring about further changes in the Journal format which other readers will appreciate.

Is the Federation now receiving your Annual Report? If not, may we have it for review?

R. E. F.

Reviews and Abstracts

Resistance of Organic Materials and Cable Structure in Marine Biological Attack. By Lloyd R. Snoke. *Bell System Techn. Jour.*, **36**, 1095.

In order to obtain information in respect to the deterioration of submarine telephone cables one way of approach presented in this paper was to subject the organic materials used in these cables to laboratory microbiological attack under aerobic and anaerobic conditions. The aerobic attack was determined by measuring the oxygen utilization by the BOD technique and the anaerobic attack was determined by the reduction of sulfate to sulfide in the presence of these organic constituents. Acclimatized seed was used in each case.

In the biochemical oxygen demand test polyethylene was not utilized by the aerobic bacteria or the anaerobic sulfate reducing bacteria. Polyvinyl chloride plasties were attacked according to the way in which they are plasticized. All the tested samples which had an added external plasticizer, including the rigid plastic, were attached to some degree. The semi-flexible polyvinyl chloride copolymers and polyvinyl chloride resin alone were not utilized by bacteria. The elastometers assayed were all attacked by bacteria, neoprine being the most resistant. The epoxide casting resin did not serve as a source of carbon for the organisms.

H. Heukelekian

Foaming of Liquids Containing Synthetic Detergents. By G. A. Truesdale. *Water and Waste Treat. Jour. (Brit.)*, **7**, 3, 108 (1958).

The effect of various factors on the intensity of foaming in the presence of detergents was measured by foam height in a glass cylinder when supplied with a constant rate of air. The detergent used was a mixture of household detergents (ABS type).

The foam produced by the addition of surface-active matter to give concentrations of 1.8, 4.5, and 8.0 mg/l in detergent-free filter effluent increased linearly with time. With low concentrations of detergent, the foam height reached a maximum in a few minutes and then broke, while with higher concentrations, the maximum height and the time required to achieve it increased. In comparing the foam with different liquids, it was found that the tendency to foam was greatest in clean water, becoming progressively less as the pollution increased.

Detergent analyses were made of the liquids before and after the formation of foam. The results showed that for a particular liquid the proportion of detergent lost from solution in producing foam was constant and was independent of the initial concentration in solution. The weight of active agent lost from solution was thus proportional to the initial concentration. A given volume of foam contained approximately the same amount of active agent irrespective of the liquid from which foam was produced.

H. Heukelekian

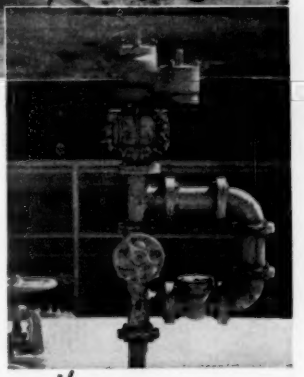
Determination of p-Cresol in Industrial Waste Waters. By G. R. Tallon and R. D. Hepner. *Anal. Chem.*, **30**, 1521 (1958).

The standard Gibbs and 4-aminoantipyrine methods do not measure p-cresol. A method is described where Gibbs reagent is used to couple with interfering phenols. The p-cresol is separated by steam distillation and is then measured by a diazzo colorimetric procedure.

R. S. Ingols

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Photos courtesy Dorr-Oliver



SAFETY-ENGINEERED "Varec" SEWAGE EQUIPMENT at new Oxnard, California Sewage Plant

FOR SAFETY'S SAKE, on this recently started 6 MGD sewage treatment plant built for the City of Oxnard, California, contractor Fred J. Early and consulting engineers Currie Engineering chose the "Varec" Fig. 5800C Pressure Relief and Vacuum Breaker with Flame Arrester, and the Fig. 211A Back Pressure Check Valve.

Over the years, "Varec" equipment's record of safety, quality and dependability has been established in thousands of communities throughout the United States and Canada. For maximum protection in the control and regulation of volatile sewage gases, be sure—specify "Varec".

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S 16

Proceedings of Member Associations

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 31st Annual Meeting of the New York Sewage and Industrial Wastes Association was held at the Park Sheraton Hotel, New York, N. Y.; Jan. 22–23, 1959. The registration was 300.

The technical program was well balanced and covered many subjects of current interest. Among the papers presented were:

"Effects of High pH on Trickling Filter Performance," by C. Richard Walter, Engineer, Hazen and Sawyer, New York, N. Y.

"Biological Treatment of Industrial Wastes," by Theodore L. Moore and J. T. Turcotte, Jr., Gibbs and Hill, Inc., New York, N. Y.

"An Investigation of the Mechanisms of Controlled Filtration," by William E. Ingram, New York University, New York, N. Y.

"Contemporary Approach to Sanitary Engineering Education," by Nelson Nemerow, Syracuse University, Syracuse, N. Y.

"Interior Sewer Photography," by William Ulrich, Sub-Surface Photo Company, Venice, Calif.

"Continuous Automatic Quantitative Sewage and Waste Analyses," by Andres Ferrari, Technicon Company, Chauncey, N. Y.

"Methodology of Free Organic Cyanides in Effluents and Chlorination Practices," by Alan H. Molof, Lederle

(*Continued on page 246a*)

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Laboratories, Pearl River, N. Y.

"Sludge Drying and Incineration," Panel Discussion.

"Evaluation of Milk Waste Treatment Processes in New York State," by William T. Ingram and Gerald Palevsky, New York University, New York, N. Y.

The featured speaker at luncheon was Dr. Stephen B. Sweeney, Director of Institute of Local and State Government, University of Pennsylvania, Philadelphia, Pa.

Greetings from the Federation were conveyed by Federation President William D. Hatfield. The Bedell Award for outstanding service to the Association went to Uhl T. Mann, Superintendent, Sewage Treatment Plant, Onondaga, N. Y., Public Works Commission. The Hatfield Award for meritorious treatment plant operation was presented to John O. Laird, Assistant Superintendent, Brighton Sewer District No. 2, Rochester, N. Y.

The new officers for the year 1958–59 are:

President: S. W. Steffensen, New York.

Vice-President: C. J. Bernhardt, Hamburg.

FSIWA Director (1962): G. A. Fleet, White Plains.

Secretary: R. C. Sweeney, White Plains.

Treasurer: D. B. Stevens, Albany.

R. C. SWEENEY,
Secretary

THE INSTITUTE OF SEWAGE PURIFICATION

The Annual Conference of the Institute of Sewage Purification was

(*Continued on page 248a*)

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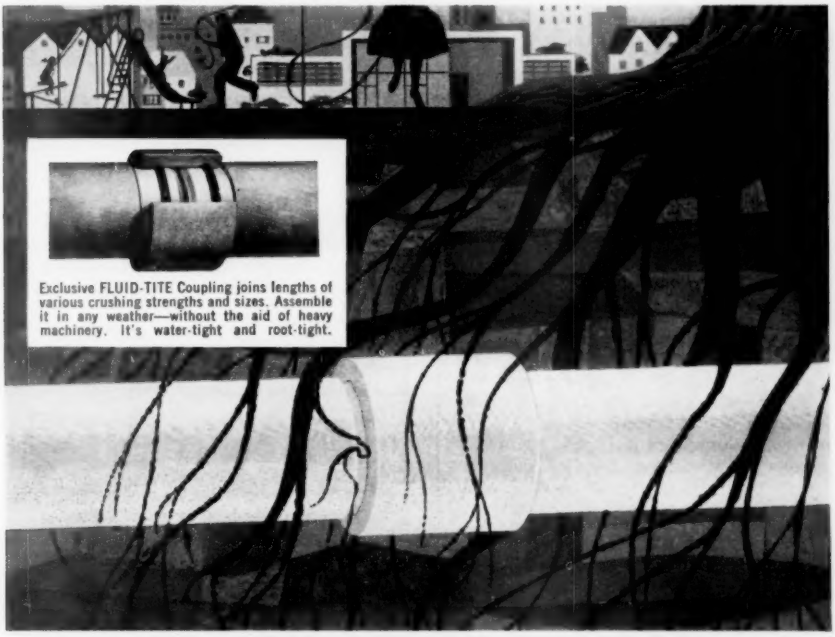
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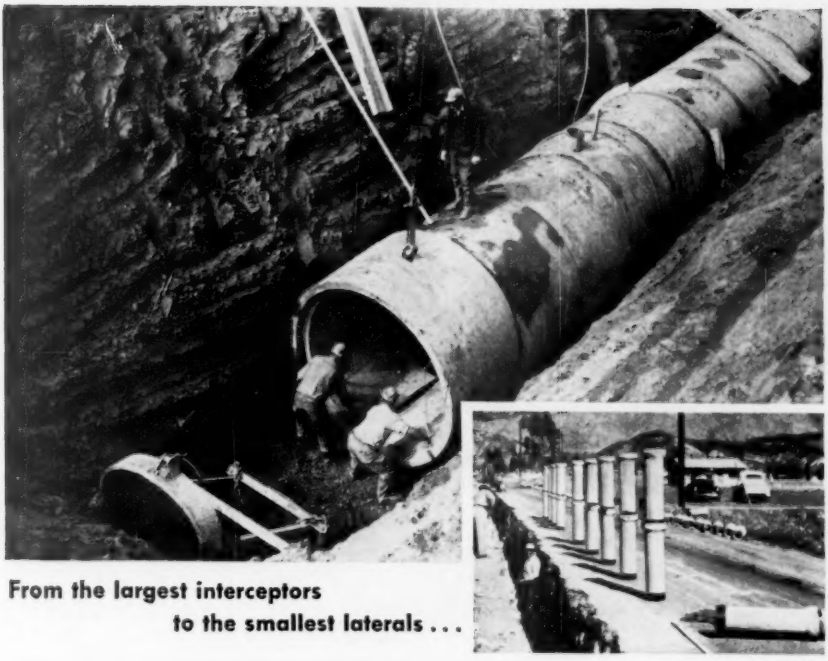

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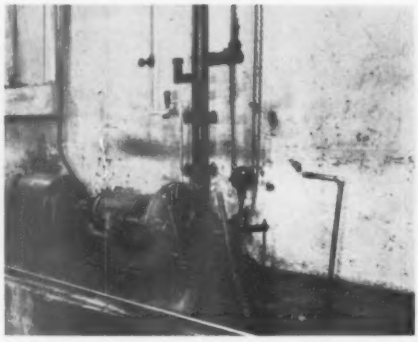

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Aspirator—A new corrosion-free, polyethylene aspirator is being marketed by Fisher Scientific Co., Fisher Building, Pittsburgh 19, Pa.

Plastic Fittings — Molded plastic fittings with grooved ends, for quick-jointing plastic pipe with Victaulic mechanical couplings, are now available. The fittings come in sizes from 1½ to 8 in. Plastic fittings for connections to flanged pipe also are available from the Victaulic Company of America, Box 509, Elizabeth, N. J.

Clarifier—A new clarifier is available which is designed to provide continuous, immediate removal of activated sludge. In operation, freshly settled sludge is guided to uptake pipes by means of deflector blades attached to the rake arms. Sludge drawn up the pipes by hydrostatic pressure flows through radial troughs to the collection basin.—Bulletin 6193, Dorr-Oliver, Inc., Stamford, Conn.

Concrete Bonding—An "alloy" of epoxy- and nylon-type synthetic resins is claimed to form a permanent joint between fresh wet concrete and cured concrete. The joint is said to be many times stronger than fully hardened concrete. The bonding material is called "Uniweld" and is manufactured by the Permagile Corporation of America, Woodside, N. Y.

Trickling Filter Media—A 32-page bulletin describes the physical properties, assembly instructions, and operational characteristics of Dowpac, the plastic packing material for trickling filters manufactured by the Dow Chemical Company, Midland, Mich.

Tool Compartments — Welded-steel tool compartments for universal mounting on any pickup or flat-bed truck are being sold by the Utility Body Company, 1530 Wood St., Oakland 7, Calif.

Rubber Pipe—The General Rubber Corp., Tenafly, N. J., has developed a special abrasion- and corrosion-resistant rubber compound, Tuflex, which is claimed to have given excellent results in systems handling abrasive and corrosive liquids, slurries, suspensions, and solids. Pipe and fittings are available in standard sizes from ½ to 72 in. ID with either duck and rubber or duck and neoprene integral full-faced flanges.

Heat Recovery Snubber—Standard, two-chamber snubbers, that are said to recover up to 1,500 Btu/bhp/hr with a circulating water pump in the system, are described in Bulletin 272. Models are available for vertical or horizontal mounting. — Burgess-Manning Company, Libertyville, Ill.

Diaphragm Pump—A new adjustable-stroke diaphragm pump is now available in sizes from a 1 in. simplex to 10 in. duplex. For additional information ask for Bulletin P8-B12, Denver Equipment Company, P. O. Box 5268, Denver 17, Colo.

Cleaner—A new, heavy-duty, safety cleaner and degreaser is furnished in high concentration to be diluted with water to clean everything from conveyors to washrooms. The cleaner is non-flammable, non-toxic, and harmless to hands. Spray application is recommended. Information on uses and dilution suggestions for Harco Safety Spray are available from the Harco Chemical Co., Cranford, N. J.

Glass-Marking Stylus—A titanium marking stylus in an anodized aluminum holder is now on the market. The stylus permits chemical and heat-resistant marking on glass, quartz, and ceramic surfaces. The layer of titanium deposited does not penetrate nor weaken the surface. The titanium marks may be removed by brief immersion in hot hydrochloric acid. The stylus, called the Glasceriber, is manufactured by the Oxford Laboratories, 111 Suter St., San Francisco, Calif., and is available from laboratory-supply houses for $2.95.

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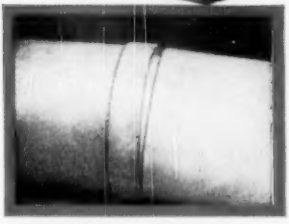

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